RESEARCH AND INNOVATION TO ADDRESS THE CRITICAL MATERIALS CHALLENGE

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY

OF THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

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December 10, 2019

RESEARCH AND INNOVATION TO ADDRESS THE CRITICAL MATERIALS CHALLENGE

TUESDAY, DECEMBER 10, 2019

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENERGY,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to notice, at 10:06 a.m., in room 2318 of the Rayburn House Office Building, Hon. Conor Lamb [Chairman of the Subcommittee] presiding.

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON ENERGY
U.S. HOUSE OF REPRESENTATIVES
HEARING CHARTER

Research and Innovation to Address the Critical Materials Challenge
Tuesday, December 10, 2019
10:00 AM EST
2318 Rayburn House Office Building, Washington, D.C. 20015

PURPOSE

The purpose of this hearing is to examine research, development, and demonstration (RD&D) needs to support the sustainable supply of critical materials for energy technologies and other applications. The hearing will focus on two topics 1) H.R. 4481 the Securing Energy Critical Elements and American Jobs Act of 2019, which would authorize Department of Energy (DOE) RD&D activities to improve critical materials recycling, reduce the reliance on critical materials through greater efficiency and material substitutes, find sustainable new critical materials sources, and better understand the critical materials supply chain and adverse impacts caused by shortages; and 2) the importance of a reliable, affordable supply of helium, which is needed as an energy technology input and for various research applications.

WITNESSES

- **Dr. Adam Schwartz,** Director, Ames Laboratory
- **Dr. Sophia Hayes,** Professor, Department of Chemistry, Washington University in St. Louis
- **Mr. David Weiss,** Vice President, Engineering and R&D, Eck Industries, Inc.
- **Dr. Carol Handwerker,** Reinhardt Schuhmann Jr. Professor, Materials Engineering & Environmental and Ecological Engineering, Purdue University

BACKGROUND

Critical Materials

Many technologies, including solar photovoltaic panels, magnets, and batteries, require materials that are only found and produced in select countries and in limited quantities. Due to these factors, the supply chains of these "critical materials" are often vulnerable to geopolitical and market forces that could ultimately inhibit the manufacture and deployment of important downstream technologies.

For example, lithium is a key input to many of the batteries found in current electric vehicles and grid-scale storage devices, and only a small number of countries have access to economically viable reserves and processing facilities. In fact, Australia, Chile, China, and Argentina produce 97.1% of the world's lithium supply, with Australia accounting for 59% of total production.[1] Without a diverse supply chain, lithium availability is particularly affected by geopolitical and market events in these producing countries. In 2010, China heightened the concerns related to critical materials supply chains when it restricted their export to Japan, which is reliant on imports to meet its domestic demand.[2]

Increasing demand for products requiring critical materials, like electric vehicles, can also strain critical materials supply. According to a 2017 report, global lithium and cobalt production would have to increase annually by 7.5% and 3%, respectively, to meet demand if there was a market breakthrough in the use of electric vehicles containing lithium batteries.[3]

Long-term, critical materials supply chains are threatened by potentially limited geologic reserves, insufficient production and facility investment, and a lack of trained professionals to support production or relevant RD&D activities.

Federal policy meant to address the critical materials challenge has traditionally focused on bolstering supply chains for defense related technologies. However, the Obama and Trump Administrations have both acknowledged the impact of critical materials on U.S. industry more broadly. Beginning in 2010, DOE published Critical Materials Strategy reports outlining demand forecasts for energy and electronics critical materials[4,5]. Further, in 2017, President Trump issued Executive Order 3817, "A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals", which asked the Department of Interior to coordinate with other relevant agencies to publish a list of U.S. critical minerals.[6]

In addition to helping identify critical materials in energy and electronics applications, DOE is conducting RD&D to mitigate U.S. vulnerabilities to global critical materials supply chains.

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[1] Critical Minerals and U.S. Public Policy. Humphries, Marc. June 28, 2019. https://www.crs.gov/Reports/R45810?source=search&guid=daa965a106df488f83f501284bb61297&index=1

[2] Amid Tension, China Blocks Vital Exports to Japan. Bradsher, Keith. September 22, 2010. https://www.nytimes.com/2010/09/23/business/global/23rare.html

[3] Critical Minerals and U.S. Public Policy. Humphries, Marc. June 28, 2019. https://www.crs.gov/Reports/R45810?source=search&guid=daa965a106df488f83f501284bb61297&index=1

[4] Critical Materials Strategy. U.S. Department of Energy. December 2010. https://www.energy.gov/sites/prod/files/edg/news/documents/criticalmaterialsstrategy.pdf

[5] Critical Materials Strategy. U.S. Department of Energy. December 2011. https://www.energy.gov/sites/prod/files/DOE_CMS2011_FINAL_Full.pdf

[6] Executive Order 13817. Federal Register. December 20, 2017. https://www.federalregister.gov/documents/2017/12/26/2017-27899/a-federal-strategy-to-ensure-secure-and-reliable-supplies-of-critical-minerals

Critical Materials Institute

In 2013, DOE established the Critical Materials Institute (CMI), an energy innovation hub led by Ames Laboratory and overseen by DOE's Advanced Manufacturing Office. DOE awarded CMI up to $120 million for five years and renewed the Institute for another, final five-year funding period extending from 2018-2023. CMI prioritizes critical materials RD&D that:

- Diversifies supply – RD&D to advance sustainable, economically viable sources of critical materials and to identify new uses for production by-products.
- Develops substitutes – RD&D to find new materials that can functionally replace critical materials and to design systems that can use such alternatives.
- Improves reuse and recycling – RD&D to enhance critical materials efficiency and to develop technologies that advance sustainable, economically viable reuse and recycling.
- Encourages cross-cutting approaches – Coordinating critical materials RD&D activities with diverse stakeholders to promote multidisciplinary approaches.[7]

During CMI's first funding period, it mostly focused RD&D activities on rare earth elements, a subset of critical materials dispersed throughout the Earth's crust that are typically difficult to economically extract in useful concentrations. It then expanded its work to include, cobalt, gallium, indium, manganese, platinum group metals, tellurium, vanadium, and battery-quality graphite for the current funding period.[8]

Rare Earth Elements Recovery

In 2014, DOE's Office of Fossil Energy began supporting the Feasibility of Recovering Rare Earth Elements Program, carried out by the National Energy Technology Laboratory in coordination with CMI, to extract critical materials from coal and coal byproducts. The program's RD&D focuses on rare earth element extraction, separation, and recovery technologies, which could "improve the economics and reduce the environmental impact of a domestic coal-based value chain." [9]

Helium

While helium is not always considered a "critical material", it was included in President Trump's list of 35 U.S. critical minerals issued in 2018.[10] Helium has a finite commercial supply and it is

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[7] Critical Materials Hub. U.S. Department of Energy. https://www.energy.gov/eere/amo/critical-materials-hub
[8] CMI Factsheet. Ames Laboratory. U.S. Department of Energy. https://cmi.ameslab.gov/materials/factsheet
[9] Feasibility of Recovering Rare Earth Elements. National Energy Technology Laboratory. U.S. Department of Energy. https://www.netl.doe.gov/coal/rare-earth-elements
[10] Final List of Critical Minerals 2018. Federal Register. May 18, 2018. https://www.federalregister.gov/documents/2018/05/18/2018-10667/final-list-of-critical-minerals-2018

needed for many research applications and commercial processes, including the development and maintenance of rocket propulsion systems, MRIs, and optical fibers.

Large helium reserves were first discovered at U.S. natural gas extraction facilities in Texas, Oklahoma, and Kansas in the early 1900s. Due in part to helium's use in many defense related technologies, the Bureau of Land Management (BLM) came to control most U.S. helium supply through the Federal Helium Reserve.[11] As directed by the Helium Privatization Act of 1996, the Federal Helium Reserve is actively reducing its stockpile and BLM is required to sell the facility by 2021. The U.S. and Qatar currently account for 85% of global helium production.[12]

In the past decade, global helium demand has increased, namely from new uses by the aerospace and semiconductor industries, and the rate of helium disbursement from the Federal Helium Reserve has slowed as the stockpile's internal pressure diminishes. These factors, coupled with relatively flat global production growth, have caused prices to rise.[13]

Due to its unique chemical properties, helium is often used by researchers to cool specialty equipment needed for experiments, such as super-conducting magnets. However, since research only consumes a small fraction of the helium market and university labs tend to have smaller budgets than private industry, the scientific community has recently struggled to maintain access to reliable, affordable helium supplies. According to a 2016 report from the American Physical Society, Materials Research Society, and American Chemical Society, some researchers have seen helium prices spike 250% since 2010.[14] Shortages of helium in the lab can cause significant and sometimes irreparable damage to equipment. These damages can cost thousands of dollars to repair and delay experiments with strict schedules.

To counter these effects, some researchers are implementing helium conservation measures and improving helium efficiency, reuse, and recycling when possible. Despite these efforts, researchers are expected to encounter helium shortages and price increases in the immediate future.[15] RD&D activities could examine ways to improve helium's efficient production and use, reuse and recycling, and equipment operability with alternative materials.

[11] The Impact of Selling the Federal Helium Reserve. The National Academies of Sciences, Engineering, and Medicine. 2000. https://www.nap.edu/read/9860/chapter/4#15
[12] Critical Minerals and U.S. Public Policy. Humphries, Marc. June 28, 2019. https://www.crs.gov/Reports/R45810?source=search&guid=b96f9eae0f964472a1d24dcac946b9f4&index=1
[13] Helium Users Grapple with Supply Crunch. American Institute of Physics. April 9, 2019. https://www.aip.org/fyi/2019/helium-users-grapple-supply-crunch
[14] Responding to the U.S. Research Community's Liquid Helium Crisis. American Physical Society, Materials Research Society, American Chemistry Society. October 2016. https://www.aps.org/policy/reports/popa-reports/helium-crisis.cfm
[15] Helium Users Grapple with Supply Crunch. American Institute of Physics. April 9, 2019. https://www.aip.org/fyi/2019/helium-users-grapple-supply-crunch

LEGISLATION

H.R. 4481, the Securing Energy Critical Elements and American Jobs Act of 2019

The Act would authorize a DOE program to carry out RD&D activities on energy critical elements to improve recycling, reduce reliance through greater efficiency and materials substitutes, and grow economically viable, sustainable sources, as well as develop more comprehensive analyses of supply chains and their market impacts. The bill allows DOE to carry out much of these RD&D activities through an Energy Innovation Hub such as the existing Critical Materials Institute. It also directs the Secretary of Energy to establish a Critical Materials Information Center to collect, catalogue, disseminate, and archive information on energy critical elements.

The bill authorizes appropriations of $30,000,00 for fiscal year 2020 with annual 5% increases, reaching $36,465,188 for fiscal year 2024, to carry out the program.

H.R. 4481 also directs the President, acting through the National Science and Technology Council, to coordinate Federal agency actions regarding critical materials, including activities to establish scenario modeling for critical materials supply chains and to promote a strong energy critical elements workforce.

Chairman LAMB. The hearing will come to order. Without objection, the Chair is authorized to declare recess at any time.

Good morning. Welcome to today's hearing entitled "Research and Innovation to Address the Critical Materials Challenge." I know that we are the primary focus of everyone on Capitol Hill today of all days, and I appreciate you all for joining us.

Today, we will be holding a hearing on the importance of rare or difficult-to-obtain materials, often called critical materials, for a wide array of energy, defense, and research applications. We'll examine a draft bill by my colleague Mr. Swalwell that will support critical materials research to improve their recycling and their ability to be replaced with more commonly available materials.

Many of the energy technologies that we're all used to that enable our modern life, including clean energy technologies, are underpinned by a host of these critical materials that are found in very limited quantities and in very few countries. This includes important technologies like electrical vehicles, solar panels, wind turbines, and other technologies used by our military and our national infrastructure. So if we continue the success of these technologies, we have to have an affordable rare-earth supply chain of these critical materials.

Unfortunately, the U.S. now relies on the importation of 100 percent of 14 of these materials and importing a partial supply of many more. The supply chain and technology application for each material is different, but it is not wise for us to rely on countries that may be adversarial to us.

To address this issue, DOE (Department of Energy) and the Critical Materials Institute are working hard to develop new sources of these materials. Experts at the National Energy Technology Laboratory (NETL), including their great team outside of Pittsburgh, are looking into ways to extract rare-earth elements out of coal and coal byproducts. And on my several visits there, they are always proud to show off a beaker of graphite solution extracted from coal that is worth about $20,000, just about this much of it. So it is possible to do. We just have to find a way to make it more economically viable. But this would provide a new resource for places like western Pennsylvania and beyond.

Behind the scenes of the research, the scientific community's work is the need for helium, which is sometimes considered a critical material and one that we do produce here in the United States. Due to its unique chemical properties, helium is essential for maintaining equipment at hundreds of labs across the country, and it's an important input into industrial processes like rocket propulsion.

Recent helium price increases have hampered our labs' work by postponing research, shifting research priorities, and at times harming equipment, all of which strain labs' budgets and slows innovation. We have to ensure that our researchers have access to the helium they need, and Federal support can play an important role here.

As with other critical materials, R&D (research and development) can play a significant role in improving our helium use efficiency, finding new sources, and developing substitutes where possible. We've heard many times on this Committee that our economic competitiveness is driven by our support for innovation, which makes this one of our top priorities. We are not guaranteed the materials to continue to research, build, and deploy the next generation of clean energy just because we have the knowledge to develop them. Accordingly, we have to strengthen our supply chain and make sure that we can safeguard our energy future, our national security, and our economic growth. That's why I'm excited to hear more about this topic, and I thank our panel of witnesses for being here today.

[The prepared statement of Chairman Lamb follows:]

Good morning and thank you to this distinguished panel of witnesses for joining us today. Today we'll be holding a hearing on the importance of rare or difficult-to-obtain materials, often called critical materials, for a wide range of energy, defense, and research applications. This hearing will also examine a draft bill introduced by my colleague, Mr. Swalwell, that would support critical materials research to improve their recycling and their ability to be replaced with more commonly available materials, as well as establish more sustainable sources of these materials.

Many of the energy technologies that enable our modern energy world, including clean energy technologies, are underpinned by a host of critical materials that are found in limited quantities and few countries. This includes important technologies like electric vehicles, solar panels, wind turbines, and other technologies utilized by our military and our broader national infrastructure. So if we are to continue the success of these and future technologies, we must ensure an affordable, reliable supply chain of critical materials. Unfortunately, due to the distribution of the supply chains for these materials, the U.S. relies on the importation of 100% of 14 materials, and the partial import of many more. While the supply chain and technology application for each material is different, it is not wise for us to rely on countries with adversarial, unstable, or unjust governments to provide materials critical to our economy, national security, and clean energy future.

To address this important issue, DOE and the Critical Materials Institute are working hard to develop new sources of these materials and improve their reuse and recycling. In fact, our experts at the National Energy Technology Laboratory, including their great team in Pittsburgh, are looking into ways to extract rare earth elements out of coal and coal by-products. Not only is this program exploring ways to secure much needed rare earth elements, it could provide a valuable new economic resource for the many people in western Pennsylvania.

Behind the scenes of energy research and the scientific community's work more broadly is the need for helium, which is sometimes considered a critical material in its own right. Due to its unique chemical properties, helium is essential for maintaining equipment at hundreds of labs across the country, like those at Carnegie Mellon, and is an important input to industrial processes like rocket propulsion. Recent helium price increases have hampered our labs' work by postponing research, shifting research priorities, and at times harming equipment, all of which strain labs' budgets and slows innovation. We must ensure our researchers have access to the helium they need, and federal support can play an important role in that process. Like with other critical materials, R&D can play a significant role in improving our helium-use efficiency, finding new sources, and developing substitutes where possible. As we've heard many times on this Committee, U.S. economic competitiveness is driven by our support for innovation, so it should be a top priority for us to ensure reliable, affordable helium for our research community.

We aren't guaranteed the materials to continue to research, build, and deploy the next generation of clean energy and other technologies just because we have the knowledge to develop them. Accordingly, we need to bolster and ensure these supply chains to safeguard our energy future, our national security, and our economic growth. That is why I am excited to hear more about how we can harness U.S. ingenuity and federally supported research to better address these issues. I thank our panel of witnesses again for being here today and I look forward to their input and feedback on these important topics and the proposed legislation.

Chairman LAMB. With that, I will turn to the Ranking Member, Mr. Weber, for an opening statement.

Mr. WEBER. Thank you, Chairman Lamb, for holding today's Subcommittee hearing. I'm looking forward to hearing from our witnesses about the energy technologies and applications being developed through critical materials research.

Critical materials, as you already pointed out, play an important role in supporting the technology that will ultimately help us change the United States' energy consumption. Whether it's lithium used in advanced batteries or helium—yes, helium is more than just party balloons in case you were wondering—in rocket propulsion systems, our resources are limited in quantity and can be challenging to develop.

And while demand is only increasing for these critical materials, supply can also be and is often restricted by geopolitical and market forces. As it currently stands, Australia, Chile, China, and Argentina produce 97 percent of the world's lithium supply, a mineral that is absolutely essential for battery technology and will be key for the expansion of electric vehicles.

So imagine if our adversaries controlled a critical material used in building the next advanced military weapon. If they were to slow down that supply or cut it off altogether, we would be at a dangerous disadvantage. Energy is just as important, and we cannot allow the advancement of technology to be limited by political or geographic forces. In order to understand our economic risk, it's vital that we assess our resources here in the United States and better understand exactly what elements and materials are vulnerable to global supply disruptions, no matter what the source.

So that is one of the reasons President Trump issued Executive Order 3817, and the Department of Interior took the first step by leading an interagency coordination to publish a list of 35 critical minerals to the American economy. But understanding our natural resources is only part of the story. Because many critical materials are very difficult to produce, it is absolutely essential that we maximize our ability to not only use and but to reuse these materials.

By extending the commercial lifecycle of these materials and investing in research to improve the efficiency of recycling and reuse, we can maximize our resources. Research can also allow us to explore opportunities to extract critical materials from new sources that were once considered, quite frankly, only waste products. We actually talked a little bit about that.

That is why DOE's National Energy Technology Laboratory, in coordination with the Critical Materials Institute or CMI, is currently conducting research on extracting materials from coal and coal byproducts. This research can help improve the economics of energy supply and production and reduce those very environmental impacts we all want to reduce. And at Ames Lab, which hosts CMI, researchers are working to improve reuse and recycling, and to expand our supply by synthesizing new materials or developing substitutes. By coordinating basic research in materials science and chemistry with early stage applied research in manufacturing, the CMI structure helps us to get the best bang for our buck and takes a holistic approach to this challenge. Our national security and our economic growth cannot be left at the mercy of a global supply chain. It just cannot happen.

I believe the Department of Energy has the capability to conduct the research and development needed to get the United States back on track as a global leader in critical materials. Dare I say that the United States leading in critical materials is our critical mission.

I look forward to hearing from our witnesses on how their research is contributing to this goal and what steps we as Congress will need to take to support those efforts.

Mr. Chairman, I yield back.

[The prepared statement of Mr. Weber follows:]

Thank you Chairman Lamb for holding today's Subcommittee hearing. I'm looking forward to hearing from our witnesses about the energy technologies and applications being developed through critical materials research.

Critical materials play an important role in supporting the technologies that will change the United States' energy consumption.

Whether it's lithium used in advanced batteries or helium - yes, it's for more than just party balloons - in rocket propulsions systems, our resources are limited in quantity and can be challenging to develop.

And while demand is only increasing for these critical materials, supply can also be restricted by geopolitical and market forces. As it currently stands, Australia, Chile, China, and Argentina produce 97% of the world's lithium supply, a mineral that is essential for battery technology, and will be key for the expansion of electric vehicles.

Imagine if our adversaries controlled a critical material used in building the next advanced military weapon. If they were to slow down supply or cut it off altogether, we would be at a dangerous disadvantage. Energy is just as important, and we can't allow the advancement of technology to be limited by political or geographic forces.

In order to understand our economic risk, it's vital that we assess our resources here in the U.S., and better understand what elements and materials are vulnerable to global supply disruptions.

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By extending the commercial lifecycle of these materials, and investing in research to improve the efficiency of recycling and reuse, we can maximize our resources. Research can also allow us to explore opportunities to extract critical materials from new sources that were once considered only waste products.

That is why DOE's National Energy Technology Laboratory, in coordination with the Critical Materials Institute or C-M-I, is currently conducting research on extracting materials from coal and coal byproducts. This research can help improve the economics of energy supply and production, and reduce environmental impacts.

And at Ames Lab, which hosts CMI, researchers are working to improve reuse and recycling, and to expand our supply by synthesizing new materials or developing substitutes. By coordinating basic research in materials science and chemistry with early-stage, applied research in manufacturing, the CMI structure helps us get the best bang for our buck, and take a holistic approach to this challenge.

Our national security and economic growth cannot be left at the mercy of a global supply chain.

And I believe the Department of Energy has the capability to conduct the research and development needed to get the United States back on track as a global leader in critical materials.

I look forward to hearing from our witnesses on how their research is contributing to this goal, and what steps Congress will need to take to support their efforts.

Chairman LAMB. If there are Members who wish to submit additional opening statements, your statements will be added to the record at this point.

[The prepared statement of Chairwoman Johnson follows:]

Good morning and thank you to all our witnesses for joining us here today to discuss a topic that is of great importance to many of our nation's industries: the supply of critical materials. There are growing concerns regarding the potential disruption of supply chains that use critical minerals for various end uses, including clean energy generation and storage technologies dependent on these raw materials. Today's hearing will help us to identify strategies for addressing these risks and provide information that will hopefully be helpful for stakeholders working in these areas.

Rare minerals are now fundamental to the functioning of our nation. They are found in alloys, magnets, batteries, and catalysts, which in turn are integrated into countless products such as aircraft, electric vehicles, lasers, naval vessels, and various types of consumer electronics. However, some of the minerals found in these applications are in limited supply and the methods for their extraction incur high environmental and financial costs. Given their necessity in so many applications, there is growing concern over whether supply can meet our societal demand in both the near- and far term.

Each mineral has its own unique story of supply and price vulnerability. For example, in my home state of Texas, the city of Amarillo justifiably calls itself the "Helium Capital of the World." Since the 1920s, the town has been home to the Federal Helium Reserve, a massive underground geological formation that acts as the U.S. strategic helium supply repository. The U.S. has long been the world's largest helium producer, but experts for years have warned of a forthcoming shortage.

You may think of helium only in terms of party balloons and perhaps the Macy's Thanksgiving Day parade, but helium has a wide array of practical uses, from crucial roles that it plays inindustrial processes, to military and civilian aerospace applications, to medical technologies and basic research, many of these uses spanning the Science Committee's jurisdiction.

As Dr. Hayes will testify today, her research with superconductors heavily depends on reliable supplies of affordable helium. We will also hear from our panel of witnesses about how there are no readily available substitutes existing for many materials, and that without action the U.S. could potentially face an annual shortfall of up to $3.2 billion worth of critical materials.

As our nation's demand for these materials rapidly increases, in step with our advancements in various technologies, I look forward to learning more from today's witnesses about how we can better support our National Labs, universities, and private companies in addressing this national challenge.

Thank you and I yield back.

Chairman LAMB. Thank you. At this time I would like to introduce our witnesses. Dr. Adam Schwartz is the Director of Ames Laboratory, one of DOE's 17 national labs. Ames Lab stewards the Critical Materials Institute, a DOE Energy Innovation Hub dedicated to researching key critical materials. Dr. Schwartz is also a Professor of materials science and engineering at Iowa State University and previously spent 23 years working at Lawrence Livermore National Laboratory researching topics such as physical metallurgy and condensed matter physics. Welcome, Dr. Schwartz.

Dr. Sophia Hayes is a Professor in the Department of Chemistry at Washington University in St. Louis covering research topics in chemistry, materials science, and condensed matter physics. She is also a co-author of the 2016 report, "Responding to the U.S. Research Community's Liquid Helium Crisis" and uses helium extensively in her research to maintain equipment and achieve very low cryogenic temperatures. Welcome, Dr. Hayes.

Mr. David Weiss is the Vice President of Engineering and Research and Development at Eck Industries, which is based in Wisconsin and produces advanced metal castings. In his role, he is responsible for the research and application of high-performance alloys and casting concepts, also the subject of over 80 papers that he has authored or co-authored. During his time at Eck Industries, the company has worked closely with DOE's Critical Materials Institute. Welcome, Mr. Weiss.

Dr. Carol Handwerker is the Reinhardt Schuhmann, Jr. Professor of Materials Engineering and Environmental and Ecological Engineering at Purdue University and leads the DOE Critical Materials Institute's focus area in recycling and reuse. Prior to joining Purdue, she served as the Chief of NIST's (National Institute of Standards and Technology's) Metallurgy Division. During her 21-

year career at NIST she led measurement R&D to improve the manufacture and performance of electronic, magnetic, photonic, and structural materials. Welcome, Dr. Handwerker.

As our witnesses should know, you will each have 5 minutes for your spoken testimony. Your written testimony will be included in the record for the hearing. And when you all have completed your spoken testimony, we will begin with questions. Each Member will have 5 minutes to question the panel. We will start with Dr. Schwartz.

TESTIMONY OF DR. ADAM SCHWARTZ, DIRECTOR, AMES LABORATORY

Dr. SCHWARTZ. Chairman Lamb, Ranking Member Weber, and Members of the Subcommittee, thank you for the opportunity to discuss the importance of research and innovation to address the critical materials challenge. And thank you for your continued strong support of physical sciences in energy research. I'm Adam Schwartz, Director of Ames Laboratory, a Department of Energy national laboratory managed by and co-located on the campus of Iowa State University.

The United States is a world leader in physics, chemistry, and materials research as a result of decades of Federal investment. To remain a world leader, the United States must continue to innovate with new materials, new products, new energy options, and new defense applications. However, new technologies in engineered materials create the potential for rapid increases in demand for some elements, thus creating the next critical material. The critical material provides essential functionality to modern engineered material, has few ready substitutes, and is subject to supply chain risk. As with most things we don't have enough of, the choice is to make more or use less.

There are two substantial DOE programs currently addressing the criticality of rare-earth elements. DOE's Office of Fossil Energy and the National Energy Technology Laboratory aim to "make more" by understanding the technical and economic feasibility of extracting and recovering rare-earths from coal and coal byproducts such as coal refuse, power generation ash, clay and shale, and acid mine drainage. Projects range from fundamental research to the design, construction, and operation of small pilot-scale facilities producing salable, high-purity rare-earth oxides.

The second major program to reduce criticality comes from DOE's Advanced Manufacturing Office. The Critical Materials Institute or CMI is conducting early stage research to accelerate the development and application of solutions to critical materials challenges, enabling innovation in U.S. manufacturing and enhancing U.S. energy security. By closely following the DOE's strategy to make more by diversifying supply and improving reuse and recycling, or use less by developing substitutes, the CMI team of national labs, universities, and industrial partners is having an impact with 309 publications, 129 invention disclosures leading to 58 U.S. patent applications, 12 awarded patents, and 9 licensed technologies.

As examples, CMI research to diversify supply aims to increase the supply of critical materials by creating more cost-effective and energy-efficient methods for the extraction, separation, and conversion of ore to metal. Momentum Technologies, a U.S. startup company, licensed two of those CMI technologies. To improve reuse and recycling, CMI developed an innovative acid-free dissolution and separation process for removing rare-earth ions from shredded hard disk drives. That process won an R&D 100 award. And for developing substitutes and newly discovered permanent magnet formulation replaces half of the precious neodymium, effectively doubling magnet production per ton of ore.

The CMI materials criticality framework is being extended well beyond rare-earths to include materials for battery and thin-film solar and LED panels. The push toward electric mobility increases the demand for energy storage elements like lithium, cobalt, and graphite. CMI research has developed technologies that can allow domestic production of two novel sources of lithium from geothermal brine and mining tailings.

In addition to all the successes and options that CMI has generated, the most important of all is the enduring capability that the team has created. It is the combination of criticality assessments, techno-economic analyses, road-mapping, and early input from industry that sets the stage for effective and efficient research into solving critical materials challenges. CMI's critical materials framework integrates expertise across the supply chains to deliver industrial-relevant technologies to diversify supply, improve reuse and recycling, and develop substitutes that are all informed and enabled by foundational science.

It is this enduring capability and collaboration that puts the U.S. in the strongest position as new materials become critical and is why CMI in particular is such an important national resource for addressing these challenges that are only going to grow more pronounced over time. Global factors, such as growth in world population, will place an even greater stress on diversification of mineral resources, the importance of innovation and creating substitute materials and the development of the science to improve the economics of reuse and recycling.

Thank you for the opportunity to testify, and again, thank you for your consistent strong support of materials and energy research. I'd be happy to address any questions or provide additional information.

[The prepared statement of Dr. Schwartz follows:]

Testimony of

Adam J. Schwartz

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Before the

Subcommittee on Energy

of the

Committee on Science, Space, and Technology

U.S. House of Representatives

Research and Innovation to Address the Critical Materials Challenge

December 10, 2019

Chairman Lamb, Ranking Member Weber, and Members of the Subcommittee, thank you for the opportunity to discuss the importance of research and innovation to address the critical materials challenge, and thank you for your continued strong support of physical sciences and energy research. I am Adam Schwartz, Director of Ames Laboratory, a Department of Energy National Laboratory located on the campus of Iowa State University in Ames, Iowa. Ames Laboratory is a single program Office of Science Laboratory with the mission to create materials, inspire minds to solve problems, and address global challenges. I am also a professor of Materials Science and Engineering at Iowa State University. Before arriving at Ames Laboratory five years ago, I spent nearly 23 years at Lawrence Livermore National Laboratory, a National Nuclear Security Administration National Laboratory in Livermore, CA.

The United States is the world leader in physics, chemistry, and materials research. Core materials science research, supported by both the Department of Energy and the National Science Foundation, has created an innovation system that is unmatched anywhere in the world. This innovation eco-system has allowed our nation to transform fundamental understanding of the chemistry and physics of materials into technologies that enhance our economic security, energy security, national security, and our quality of life. From computers and cell phones to wind turbines and electric vehicles, to key defense systems, our country has reaped tremendous benefits because of decades of Federal investment in academia, national laboratories, and scientific user facilities. To remain a world-leader in these crucial security areas, the United States must continue to innovate with new materials, new products, new energy options, and new defense applications.

At the heart of most technological advances are sophisticated, engineered materials carefully designed to provide desired functions that exploit the unique characteristics of chemical elements. Early cell phones in the 1980s consisted of materials that used approximately 30 elements from the periodic table. Today's smart phones contain 60-70 different elements, each one performing a very specific function. New technologies and engineered materials create the potential for rapid increases in demand for some elements that until now have only been needed in small quantities.

What are critical materials and why are they so critical?

A critical material provides essential functionality to a modern, engineered material, has few ready substitutes and is subject to supply-chain risk. In the short-to-medium term (a year or two, up to about a decade), these risks may be due to unexpected demand growth that overwhelms existing production capacity or otherwise risky supply chains due to lack of supply diversity, geopolitical risks, or other factors. In the long term (more than a decade), risks may be due to geological scarcity of resources, lack of efficient and non-polluting production technologies, insufficient human capital, or insufficient investment.

Exactly what is "at risk" depends on the circumstance. To a single company or a sector of the economy (such as manufacturing), production, employment, and profits are at risk if supply chains are insecure; additionally, a company's reputation may be at risk if it relies on sources of production that damage the environment. The natural environment may be at risk if existing production technologies significantly degrade human health or ecosystems as part of producing a critical material. The development and deployment of desirable new technologies (such as electric vehicles) may be at risk if materials scientists and engineers avoid using a specific material providing the best functional properties because of fear the material will be unavailable in sufficient quantities at prices customers are willing to pay.

A recent example of materials criticality occurred in 2010, when the prices of materials based on the rare-earth elements spiked, in some cases rising to 25 times their prior values. While rare-earth elements are typically used in relatively small quantities, they are functionally essential, and presently irreplaceable in a wide range of industries, including the production of clean energy technologies. The most prominent examples – although by no means the only – are two of the rare-earth elements, neodymium and dysprosium, used in permanent magnets for electronics, high-efficiency motors, the most energy-efficient wind turbines, and key defense systems. To address the rare-earth supply challenges, the United States, Japan, the European Union, and others responded to the spike in rare-earth prices through various approaches. The U.S. Department of Energy's 2011 Critical Materials Strategy outlined a three-pronged approach to supply-chain shortfalls:

- Achieve globally diverse supplies: A major factor causing criticality is the concentration or location of supply in a single company, country, or region.
- Identify appropriate substitutes: For example, develop substitutes for materials like magnets or phosphors that use little or none of the critical elements.
- Improve capacity for recycling, reuse, and more efficient use of critical materials: Minimizing the draw-down of existing supplies by improving manufacturing efficiency and enhancing recycling and re-use.

As with most things we don't have enough of, the choices are to make more or use less.

To implement this strategy, DOE competed an Energy Innovation Hub and established the Critical Materials Institute in 2013, led by Ames Laboratory. The Critical Materials Institute, or CMI, closely follows the DOE strategy to make more by diversifying supply and improving reuse and recycling, or use less by developing substitutes. Its work focused initially on the rare-earth elements, but its methods and approaches have been extended to include lithium and cobalt for batteries and gallium, indium, and tellurium in thin-film solar and LED panels.

Before I describe current research efforts and the lessons learned, I want to take a moment to look forward to where new science and technology are required and where advances will lead our nation. World population continues to grow as does the middle class. These global factors will place an even greater stress on diversification of mineral resources, the importance of innovation in creating substitute materials, and the development of the science to improve the economics of reuse and recycling. As our science and innovation engine turns its focus toward quantum information systems, strategies known to mitigate supply chain risks – diversification of supply, materials substitution, and efficient manufacturing and recycling – must be incorporated into research and development efforts. Other important advances in energy research include higher efficiency energy power plants based on new materials designed to withstand harsh service environments, next-generation energy storage to facilitate widespread adoption of electric mobility and the deployment of clean energy technologies, and the revolutionary conversion of refrigeration from 100-year-old vapor compression technology to high efficiency solid-state cooling. All of these advanced energy technologies will require robust and resilient supply chains integrated across the materials lifecycle from source to final product and end-of-life.

Critical Materials Research and Development Efforts

Ames Laboratory, other DOE National Laboratories, and universities were studying critical materials well before they were defined as "critical." It is important to remember that current research, recent success, and all future options are based on years, or decades, of prior research. DOE supports fundamental scientific research through the Basic Energy Sciences program within the Office of Science. Core research in fundamental physics, chemistry, and materials provide foundational understanding for first principles predictions of highly complex materials, separations science (the science of extracting one element from another), and the discovery of new materials with enhanced functionality. This core research establishes the scientific knowledge upon which solutions to technological barriers along entire supply chains are based. In addition, investment in world-class research tools like x-ray synchrotrons, neutron scattering facilities, and leadership-class computers and algorithms have all set the stage for the materials advances and the resulting energy independence that this nation now enjoys. The sustained investment in the National Laboratories and academia coupled with unparalleled scientific user facilities has created the flexible platform on which the nation is addressing the challenge of materials criticality.

There are two substantial DOE programs currently addressing the criticality of rare-earth elements: the Critical Materials Institute, a DOE Energy Innovation Hub funded by the Office of Energy Efficiency and Renewable Energy, and the Feasibility of Recovering Rare-Earth Elements Program, funded by the Office of Fossil Energy and the National Energy Technology Laboratory (NETL).

The Office of Fossil Energy and NETL initiated the Feasibility of Recovering Rare-Earth Elements Program in 2014 in response to the Congressional request for understanding the technical and economic feasibility of extracting and recovering rare-earth elements from coal and coal by-products. The program consists of projects ranging from fundamental research efforts to the design, construction, and operation of small pilot-scale facilities, producing salable, high purity, rare-earth oxides. To date, in conjunction with NETL, approximately 25-30 projects have been actively conducted at universities, National Laboratories, and small businesses, using 300 part-per-million rare-earth-containing coal-based materials such as coal, coal refuse from preparation plants, power generation ash, clay and shale over/under-burden materials, as well as acid mine drainage (AMD) and sludge.

Numerous technical insights and innovations have resulted since this effort began. As examples,

- Nearly 100% of the rare earth content contained in coal-based acid mine drainage can be easily removed, producing extracts that are enriched with higher heavy rare-earth element concentrations in comparison to rare earths produced from other coal-based materials.
- Identification that approximately 80-95% of the rare earth content in lignite coals is in organically associated phases, which are easily extractable, and perhaps comparable to that of rare-earth elements produced from off-shore ion exchangeable clays.
- Development of fiber optic sensors that are capable of detecting *in-situ* part-per-million concentrations of rare earths in liquidus media.

Currently, DOE-NETL has three domestic, first-of-a-kind, mixed rare earth oxide pilot-scale facilities operating, producing small quantities of high purity (maximum 80-90%) rare earth oxides from coal refuse from central Appalachian and Illinois coal basin materials, from northern and central Appalachian acid mine drainage, and from power generation ash produced from eastern Kentucky coals – all turning coal waste materials into potentially remediated and valuable revenue streams.

For the near future, DOE-NETL's efforts will continue to be focused on

- Improving the efficiency and optimization of current rare earth extraction processes, enhancing rare earth extraction and recovery system economics.
- Recovering critical minerals and materials during production of rare earths from domestic coal-based resources.

- Accelerating process scale-up from small pilot to near commercial facilities, that potentially could incorporate advanced, transformational, rare earth extraction and separation processes.
- Producing high purity, individually separated, salable, rare earth oxides from domestic coal-based feedstock materials.
- Continuing development of metallization processes that convert rare earth oxides into rare earth metals for alloying.

The second major thrust to reduce criticality comes from the DOE Energy Efficiency and Renewable Energy's Advanced Manufacturing Office.

The Critical Materials Institute is conducting early-stage research to accelerate the development and application of solutions to critical materials challenges – enabling innovation in U.S. manufacturing and enhancing U.S. energy security (https://cmi.ameslab.gov/). The team is comprised of four National Laboratories, nine universities, and 15 industrial partners. There are 22 industry, academic, and government affiliate members. CMI has the structure and the connectivity to access facilities and researchers from the Office of Science and EERE as needed.

Rare-earth elements are the most prominent of the critical materials today. CMI aims to develop economically viable processing techniques for improved availability of critical materials for clean-energy technologies, develop new techniques to recover them from waste and scrap, and find acceptable alternatives for use in devices such as generators, motors, lighting, and magnets.

Based on early-stage foundational research, CMI has filed 129 invention disclosures, leading to 58 U.S. patent applications and 12 awarded patents that address rare earth separations for primary metal refining or recycling processes and new magnet compositions and processes.

Diversifying Supply

CMI research to diversity supply aims to increase the supply of critical materials by creating more cost-effective and energy efficient methods for the extraction, separation, and conversion of ore to metal. Generally grouped together as upstream activities, research has focused on developing co-production from existing domestic productions sources. These sources include primary mineral operations such as copper, phosphates, and borax. Advances in computational designs of separation chemistry with enhanced elemental selectivity and improvements in membrane separation has been most effective in reducing processing steps that lower both capital expenditures and operational costs.

Although rare-earth elements remain high on the list of critical materials, the push toward electric mobility increases the demand for energy storage elements like lithium, cobalt, and graphite. CMI is addressing these critical elements as well. Efforts have resulted in new lithium capture technologies for a domestic lithium supply. While the U.S. possesses plentiful lithium resources to not only become self-sufficient in supplying its own needs for battery production, but also to become a net exporter, its current output is small compared to overall global production. Research results obtained by CMI and its partners have led to technologies that can allow domestic production from two novel sources of lithium: geothermal brine and mining tailings. CMI's technologies include a new sorbent that can extract lithium at only several hundred ppm from geothermal brine, a membrane-based method for concentrating the recovered lithium so that a solid lithium product can be obtained, and a new solvent extraction method that can pull impurities out of lithium solutions to produce battery-grade lithium.

Diversifying supply research has also yielded a breakthrough in the economics of synthetic graphite production. Graphite is, along with lithium and cobalt, one of the critical materials used for the production of batteries needed for electric vehicles and grid storage. Unfortunately, graphite is costly to produce from plentiful sources of amorphous carbon such as coal and biomass. Recently, CMI researchers, discovered a way to reduce the processing temperatures from 3100°C to 800°C through electrolysis in a molten salt. This process lowers the energy consumption 90%, shortens the time from days to hours, and leads to potential cost reductions of 50%. Several U.S. companies have already indicated an interest in licensing opportunities.

Reuse and Recycling

Dysprosium, a particularly critical rare-earth element is added in small quantities to improve high temperature performance of rare-earth magnets. CMI scientists developed a new separation technology based on membrane solvent extraction that efficiently and economically separates dysprosium from mixed rare earth solutions, with significantly reduced amounts of acid than conventional methods. This technology has recently been granted a U.S. patent and licensed by Momentum Technologies, a U.S. start-up company that is commercializing an earlier CMI technology for creating high purity mixed rare-earth solutions.

A key step in transforming recycled rare-earth magnets into feedstock for new rare-earth magnets is converting the separated rare-earth oxides into metal. Researchers have developed a commercially viable technology with low environmental impact for reduction of rare-earth oxides into metal. Detailed techno-economic analyses at the earliest stages of research helped the researchers identify and eliminate economic and environmental barriers before significant resources were invested in development of less-than-optimal technologies.

The CMI team has also developed an innovative acid-free dissolution and separation process for removing rare-earth ions from shredded hard disk drives. This process won an R&D 100 award and a Notable Technology Development Award from the Federal Laboratory Consortium.

Developing Substitutes

CMI research in developing substitutes provides alternative choices to usage of the critical materials. Often believed to be drop-in replacement materials, substitution can also be process for process, device for device, or system level substitutions. CMI has developed new materials and processes for both lighting and permanent magnets. The team has discovered suitable green and red lamp phosphor substitutes, reducing the use of the rare earth terbium by 90% and eliminating the use of the rare earth lanthanum for green phosphors, and eliminating the use of rare earths europium and yttrium in red phosphors. Industry is currently assessing the feasibility for commercial lighting via full manufacturing trials. New permanent magnets formulations containing less or no critical elements have been discovered including a formulation that replaces half the Nd in $Nd_2Fe_{14}B$ with lanthanum (La). Since La is a main component in rare earth ore and generally exceeds the amount of Nd, addition of La does not require additional processing, effectively doubling magnet product per tonne of ore. Another new magnet is a "gap magnet" containing no critical elements that will replace rare earth magnets in certain applications where currently only rare earth magnets are in use. Finally, CMI is using advanced manufacturing to print magnets that can triple magnetic performance of low-grade rare-earth magnets, effectively reducing the amount of critical materials needed for a given application.

An Integrated Research Model

An integrated research model coordinating early and later stage R&D that couples fundamental science with scale-up demonstration and commercialization is required to address the full spectrum of R&D needs over the entire supply chain. Cross-cutting fundamental research efforts produce basic knowledge, information, or tools that are of specific value to the applied research, development, and demonstration (RD&D) projects. These types of projects generally do not produce intellectual property and are characterized by very low technology readiness levels. Research outcomes from this type of work are generally published in the open literature and made available through the usual means. As RD&D efforts proceed to higher readiness levels, interactions with the private sector become increasingly more important.

For one example, in pursuit of new magnet materials to replace neodymium-iron-boron, CMI has adopted an approach that includes computer simulations, experimental exploration of candidate alloy compositions using combinatoric methods, and rapid analysis and testing. These methods are each founded in tools previously developed in academia and National Laboratories but they have been advanced and made specifically useful in addressing critical materials. Among many other advances of this kind, CMI has:

- Developed the first successful computer model for predicting magneto-crystalline anisotropy in proposed new materials – an essential contribution from fundamental condensed matter physics in support of developing new magnet materials.
- Developed a new tool, based on additive manufacturing technologies, which allows for the rapid production of target magnet compositions at manufacturing scale. This tool along with the two below, was used to validate the computer code described above.
- Added new capabilities for rapid structural and chemical analysis of materials that take advantage of the additive manufacturing tool described above.
- Added high-throughput magnetic testing capabilities.

All of these capabilities work with each other to address the challenge of critical materials, but they also enhance the capabilities of other Office of Science and AMO programs. Bringing together capabilities across all of CMI's participating institutions, across a wide spectrum of basic and applied research, CMI has created a range of candidate materials for new high-performance magnets.

While it is conceivable that these advances could have been made without the existence of CMI, under the usual operating procedures, even this simple case would have required traditional funding through four separate projects to develop the tools, and then a fifth funded program to work on the desired material. It has been our observation that progress toward our goal of technology adoption is accelerated – often very considerably – when industry input is obtained early and often during early-stage research efforts. Interactions with industry allow for and promote increasingly intense collaborations as an R&D effort moves from early stage toward demonstration.

Summary and Conclusions

No single institution has all the expertise to solve the full range of critical materials challenges. Large teams, like the Energy Innovation Hubs, bring together expertise from around the country. In addition to all the successes and options that CMI has produced, the most important of all is the enduring capability that CMI has created. It is the combination of criticality assessments, techno-economic analyses, roadmapping, and early input from industry that sets the stage for efficient and effective research into solving critical materials challenges. CMI accelerates the development and application of solutions to emerging or existing critical materials challenges for the benefit of U.S. manufacturing and the global clean energy economy. CMI's critical materials framework integrates expertise across the supply chains to deliver industrially-relevant technologies to diversify supply, improve reuse and recycling, and develop substitutes – both informed and enabled by foundational science.

It is this enduring capability and collaboration that puts the U.S. in the strongest position as new materials become critical and is why CMI in particular is such an important national resource for addressing these challenges that are only going to grow more pronounced over time.

Dr. Adam J. Schwartz is Director of Ames Laboratory, a Department of Energy National Laboratory located on the campus of Iowa State University in Ames, Iowa. He is also a professor of Materials Science and Engineering in the College of Engineering at Iowa State University. Ames Laboratory is a single program Office of Science laboratory with the mission to create materials, inspire minds to solve problems, and address global challenges. Prior to joining Ames Laboratory in 2014, he had nearly 23 years of materials science research and management experience at Lawrence Livermore National Laboratory in Livermore, CA that spanned physical metallurgy to condensed matter physics with a particular focus on phase transformations, phase stability, and electronic structure of actinides and lanthanides. He held leadership positions for Plutonium Aging, Dynamic Properties of Materials, and Physics and Engineering Models programs. He led the Lawrence Livermore National Laboratory team during the development of the Critical Materials Energy Innovation Hub then continued on as the Developing Substitutes Focus Area Leader. In this role, he leveraged his expertise in metallurgy, condensed matter physics, and technical management to drive the innovation of substitute materials. Dr. Schwartz has authored over 100 journal articles, monographs, book chapters, technical reports and co-edited two editions of *Electron Backscatter Diffraction in Materials Science* (Kluwer Academic/Plenum Publishers, 2000; Springer, 2009). Dr. Schwartz holds B.S. and M.S. degrees in Metallurgical Engineering and a Ph.D. degree in Materials Science and Engineering from University of Pittsburgh.

Chairman LAMB. Thank you, Dr. Schwartz. Dr. Hayes.

TESTIMONY OF DR. SOPHIA HAYES, PROFESSOR, DEPARTMENT OF CHEMISTRY, WASHINGTON UNIVERSITY IN ST. LOUIS

Dr. HAYES. Chairman Lamb, Ranking Member Weber, and Members of the Subcommittee, thank you for the opportunity to discuss the importance of research and innovation on these critical materials. I'm Sophia Hayes, Professor of Chemistry at Washington University in St. Louis. And, as eloquently put by you both, I'm a researcher who uses liquid helium in my own research program for cryogenic applications, as well as to sustain instruments.

I'd like to highlight that my instruments are not all that uncommon. These are used in every pharmaceutical company, every R&D department of oil and gas companies, commodity and chemical companies, and also at every university within the United States that has a major science and engineering program.

So imagine a future time when helium is in short supply, where access to such instruments may become more limited or shut down. Medical diagnostic imaging could also become less accessible and where the latest handheld electronic device also slows in production, all for want of this commodity chemical.

So let me share my research community's experiences as a reflection of the broader community's needs. Helium is an element, as you pointed out, with many, many special properties. It's lighter than air. It is inert or unreactive, and it also can achieve low temperatures, lower than any other substance we have on Earth. And instruments like mine require helium to operate. They cannot function without it. But liquid helium evaporates as it's being used, and therefore, it must be replenished.

What we have faced in the past 2 decades are 2 problems. One is steep price increases and the other is supply shocks where helium could not be acquired in some cases at any price. The origin of the price increases come from a market that's highly volatile. At my institution the price for liquid helium has increased more than 400 percent during my career, but the grants that we receive remain flat, not accounting for such massive inflation in the price of this line item in my budget. For researchers like myself it means I have to choose between paying for helium or paying the salary to support a graduate student getting a Ph.D. In my case I've had to decommission magnets, reducing my lab's research capacity.

Even more critical than price is supply insecurity. A supply shock lasting weeks or even a month can be disastrous. My magnets need to be filled every 4 weeks, so a delay of even 2 to 3 weeks is a crisis. And importantly, if my supply is cut, it's likely that it's being felt regionally. We've had several major supply shocks in my career, the most recent as a result of the Qatar blockade, and multiple minor supply shocks.

Given these, forward-thinking civil servants and some of our professional scientific societies have tried to come to our community's rescue. For several years the Defense Logistics Agency, in collaboration with the American Physical Society and American Chemical Society, were able to provide program participants a reliable source of helium at lower prices than they could negotiate on their own, helping to protect smaller-scale university users who receive Federal funding. Unfortunately, we just learned this program will be discontinued in January, in part due to the turbulent helium market, showing how incredibly challenging this situation is.

This purchasing program helped researchers reduce helium costs and mitigate pricing issues in the near-term, but our irreplaceable helium resources continue to be depleted, and reducing our long-term use of helium is essential.

With this in mind, we must enable as many academic researchers as possible to reduce their helium consumption without compromising their programs, their research programs. National Science Foundation's (NSF's) Division of Materials Research is helping a small number of researchers reduce their helium use and save the government money over time by providing funding for the purchase of helium recyclers. This program is successful but far too modest to address the problems we are facing.

In my opinion the NSF program should be looked at as a model, and Congress should ask Federal agencies to support the wide-range adoption of helium recycling equipment. This will require agencies to invest in the capital equipment infrastructure necessary to make helium recycling commonplace. Unless funding is dedicated to help address this issue, the U.S. risks losing the research capacity responsible for many significant breakthroughs in areas such as medicine, national security, and fundamental science.

Additionally, while outside the jurisdiction of this Committee, it is important to recognize that the U.S. Strategic Helium Reserve, which is scheduled for shutdown in fall 2021, is a central component of the domestic helium supply. Storage of an inventory of helium is critical for the health of our helium supply infrastructure.

Thank you for this opportunity to testify. I and my colleagues will work with the Committee at any time now or in the future to help maintain the Nation's security and economic competitiveness by ensuring this vital resource is preserved. Thank you.

[The prepared statement of Dr. Hayes follows:]

Testimony of Sophia E. Hayes

Professor of Chemistry, Washington University in St. Louis

St. Louis, MO 63130

Before the

Subcommittee on Energy

of the

Committee on Science, Space, and Technology

U.S. House of Representatives

Research and Innovation to Address the Critical Materials Challenge

December 10, 2019

Chairman Lamb, Ranking Member Weber, and Members of the Subcommittee, thank you for the opportunity to discuss the importance of research and innovation to address the critical materials challenge, and thank you for your continued strong support of physical sciences and energy research. I am Sophia Hayes, Professor of Chemistry at Washington University in St. Louis. I am a researcher who uses liquid helium extensively to both sustain instruments and to achieve very low cryogenic temperatures in my research.

Overview: helium touches nearly all lives

Helium is the second element on the periodic table (which I note because this is the International Year of the Periodic Table) and as a result, it is very, very small. Helium is so small that, unlike other gases, it will escape out of anything it is contained in, including the cylinders we temporarily store it in for immediate use and ultimately the Earth's atmosphere itself. Eventually, all the helium on earth will escape, and because we cannot make more of it on any realizable time-scale, it is the very definition of a non-renewable resource.

Helium is ubiquitous in our lives. It is an element of great importance for a large number of activities and products. It's used to cool magnetic resonance imaging (MRI) machines in medicine; to pressurize the rockets' fuel systems necessary to launch space missions; to manufacture the semiconductor chips, flat panel screens, and optical fibers that dominate our electronic "lives" and handheld devices; and as a critical element in red lasers. Helium is essential for each one of these processes. Helium use is of course also close to our hearts in the fun and fanciful uses for party balloons and the massive balloons in, for example, the Macy's Thanksgiving Day Parade.

Helium has two very special properties: 1) as a gas, it is used in balloons and lifting applications because it is lighter than air, and 2) when it is a liquid, it is the coldest substance on Earth, allowing us to cool down materials and use special "states of matter" – such as the superconducting state that is at the core of every magnetic resonance imaging machine or any other device that relies on extremely powerful magnets, like the particle colliders used by high energy physicists. In other words, without helium, these applications become closed off to us.

Research Community

I'm here to discuss the research community's experiences and needs.

Helium is an element with many, many special properties – sometimes it will be useful to speak in analogies to make this exotic "chemical" more relatable.

Where helium has absolutely no substitute – is in cooling applications.

In practically every chemistry department in the U.S., there are instruments for "fingerprinting" molecules that require a constant supply of dozens of liters of liquid helium. These instruments are called nuclear magnetic resonance (NMR) machines – and these are close counterparts of the magnetic resonance imaging (MRI) machines used in medicine. (For ease of expressions, let's call both "magnetic resonance.")

These instruments *require* helium to operate; they cannot function without helium. Like the radiator in your car, these need to be filled with liquid helium as a kind of cooling fluid that is circulated around the components – that cooling fluid allows materials inside the instrument to achieve a superconducting state.

But liquid helium evaporates as it is being used and therefore must be replenished. If the liquid helium runs low, the components inside will stop superconducting, catastrophically generating incredible amounts of heat, potentially melting and destroying components on the inside of the instrument. For want of a dozen or so liters of liquid helium, capital equipment costing anywhere from $100K to $15M will be destroyed.

At my university, we have more than 2 dozen such instruments spread amongst 4 academic departments. These are essential for both conducting our cutting-edge experiments and training the next generation of scientists (chemists, physicists, materials engineers, and medical doctors).

Now, imagine there are 900 – 1000 academic departments in the U.S., with at least one, and often multiple magnetic resonance machines – all dependent on this sustaining chemical.

Moreover, this extends heavily into industry as well. Every pharmaceutical company, every research and development arm of oil and gas companies (such as Exxon Mobil, Chevron), and every chemical-producing company has one or more magnetic resonance machines. These instruments help researchers understand what they create in the lab when they combine chemicals to make new molecules. The advent of magnetic resonance in the 1960s and 1970s and its entry into industry was a game-changer. There is an analysis of the number of known or lab-synthesized chemicals tracked by decade (Chemical Abstracting Service, American Chemical Society), and there was explosive growth after the introduction of magnetic resonance, from hundreds of thousands of known chemicals in the 1960s to over 5 million chemicals by 1980 and tens of millions of chemicals today.

So magnetic resonance permeates all of chemistry. Some estimates put the total number of helium-using magnetic resonance magnets in the U.S. at 5000 of more, and this does not include medical instruments.

In physics, researchers search for exotic quantum states of matter by cooling experiments to extraordinarily low temperatures. It's so cold, we use a different temperature scale to make it easier for us to talk about. Temperatures from what's called "1 milli-Kelvin to 4 Kelvin" are regularly achieved. That's approximately -460 Fahrenheit to -452 Fahrenheit.

Finally, in medicine, nearly all hospitals depend on magnetic resonance imaging (MRI) instruments for life-saving medical diagnoses. MRIs can determine structures in soft tissue – that eludes detection by X-ray, or other scanning technologies, like positron emission tomography (PET) imaging.

Statement of the Problem

I hope I've made obvious the tremendous need for a reliable supply of (liquid) helium in the scientific research and medical diagnostic communities.

What we have faced in the past two decades is:

1) Steep price increases
2) Supply "shocks" – where helium could not be acquired in some cases at any price.

The origin of price increases comes from a market that is highly volatile. This is in an area of "resource economics" that is outside my area of expertise. I can simply comment that for researchers like myself who receive fixed budgets from the National Science Foundation, we cannot weather the tremendous price increases we have seen.

At my institution, the price for liquid helium has increased more than 400% from the start of my career – but the grants we receive have been flat, not accounting for such massive inflation in the price of a critical line-item in budgets. For researchers like myself, it means I have to choose between paying for helium or paying the salary to support a graduate student in getting a PhD. In my case, I have had to decommission magnets – reducing my lab's research capacity – simply because I couldn't afford to purchase the helium necessary to sustain them.

Even more critical than price is supply insecurity. Our magnetic resonance instruments need a regular supply of helium, as I mentioned earlier. A supply shock, lasting weeks or even a month can be disastrous. Helium vendors simply tell us that we are being "allocated" only a fraction of what we order – or in some cases none at all. In the meantime, the reservoir on these instruments gets lower and lower by the day (from evaporation of the helium). My magnets need to be filled every 4 weeks, so a delay of even 2- or 3-weeks is a crisis. Importantly, if my supply is cut, it is likely that this is being felt regionally, meaning it's affecting magnetic resonance machines across universities, industries, and hospitals.

We have had several major supply shocks in my career – the most recent as a result of Qatar blockade – and multiple minor supply shocks. If you'll permit me to use another analogy, we are like cattle ranchers. We have a handful of magnets in our "herd" that will die during a drought. If they die, these magnets never come back. We can buy new ones, certainly, a massive capital expenditure, but know that we will face future droughts that could "kill off" the herd again.

Attempted Solutions

Given these supply shocks, forward-thinking civil servants and some of our professional scientific societies have tried to come to our community's rescue. It's important to mention these efforts, because there are people creatively fighting behind the scenes to find solutions.

Dr. Dan Finotello at the National Science Foundation crafted a program to use funds for a small number of helium recycling units for researchers within the Division of Materials Research program. Helium recyclers are large capital expenditures, but they substantially reduce the risk to those researchers who are fortunate enough to secure them. This equipment can dramatically reduce the amount of helium researchers need – the recycling efficiency can be 95% or higher – helping conserve grant funds and an irreplaceable resource.

Douglas Smith from the Defense Logistics Agency (DLA) and Dr. Mark Elsesser from the American Physical Society worked together to create a program for academic researchers that sourced helium through DLA. The American Chemical Society joined forces with this program, creating an APS-ACS Liquid Helium Purchasing Program. Quoting them: "the DLA, which is permitted to purchase liquid helium via the in-kind program on behalf of any federal grantee, serves as a "broker" for program enrollees. By combining its customers' needs, DLA substantially increases its purchasing power when negotiating contacts and price. Additionally, DLA offers a more reliable liquid helium procurement route — DLA has established relationships with multiple liquid helium suppliers and their customers are not tied to a single vendor."

For several years, DLA was able to provide program participants a reliable source of helium at lower prices than they could negotiate on their own, helping to protect smaller-scale university users who receive federal funding. Unfortunately, this program will be discontinued in January – in part due to turbulent helium market – showing how incredibly challenging this situation is.

Policy Recommendations

The APS-ACS program helped researchers reduce helium costs and mitigate pricing issues in the near-term. But our irreplaceable helium resources continue to be depleted and reducing our long-term use of helium is essential. With this in mind, we must enable as many academic researchers as possible to reduce their helium consumption without compromising their research programs.

As I mentioned previously, NSF's Division of Materials Research is helping a small number of researchers reduce their helium use – and save the government money over time – by providing funding for the purchase of helium recyclers. This program is successful, but far too modest to address the problems we are facing.

In my opinion, the NSF program should be looked at as a model, and Congress should ask federal agencies to support the wide-range adoption of helium recycling equipment. This will require agencies to invest in the capital equipment infrastructure necessary to make helium recycling commonplace. Unless funding is dedicated to help address the issue, the U.S. risks losing the research capacity responsible for many significant breakthroughs in areas such as medicine, national security and fundamental science.

Additionally, while outside the jurisdiction of this Committee, it is important to recognize that the U.S. Strategic Helium Reserve, which is scheduled for shutdown in fall 2021, is a central component of the domestic helium supply. Storage of an inventory of helium is critical for the health of our helium supply infrastructure. In the past, the Reserve has provided a vital bulwark against shocks to helium supply, ensuring that federal research and defense needs were insulated from disruption.

Given that we continue to experience helium supply disruptions, Congress should postpone the planned 2021 shutdown and sale/ privatization of the Strategic Helium Reserve, until the helium supply chain has been made more resilient to supply shocks and price spikes.

Thank you for the opportunity to testify. I and my colleagues will work with the Committee at any time now or in the future to help maintain the nation's security and economic competitiveness, by ensuring this vital resource is preserved.

Prof. Sophia E. Hayes is a Professor of Chemistry at Washington University in St. Louis, Missouri. Her research is centered on nuclear magnetic resonance, especially at very low temperatures, spanning topics in chemistry, materials science and condensed matter physics. Her research is wide-ranging, addressing new materials for carbon capture, metal oxide thin films, and quantum-mechanical phenomena in semiconductors. Washington University has long been a leader in the field of magnetic resonance, in multiple departments and disciplines, spanning physical sciences and medicine. Hayes is a co-author of the 2016 report "Responding to the U.S. Research Community's Liquid Helium Crisis" issued jointly by the American Physical Society, Materials Research Society, American Chemical Society (https://www.aps.org/policy/reports/popa-reports/upload/HeliumReport.pdf). She has taken an active role to raise awareness of helium supply issues internationally.
Prof. Hayes holds B.S. and Ph.D. degrees in chemistry from Univ. of California Berkeley, Univ. of California Santa Barbara, respectively. She was a Directorate Postdoctoral Fellow at Lawrence Livermore National Laboratory in the Division of Chemistry & Materials Science (jointly with U.C. Berkeley, Chemical Engineering), and she was an Alexander von Humboldt Fellow in Physics at Technical University of Dortmund, Germany.

Chairman LAMB. Thank you, Dr. Hayes. Mr. Weiss.

TESTIMONY OF MR. DAVID WEISS, VICE PRESIDENT, ENGINEERING AND RESEARCH AND DEVELOPMENT, ECK INDUSTRIES, INC.

Mr. WEISS. Chairman Lamb, Ranking Member Weber, and Members of the Subcommittee, thank you for giving me the opportunity to appear before you today. My name is David Weiss, and I'm Vice President of Engineering and Research and Development for Eck Industries, Incorporated, located in Manitowoc, Wisconsin.

We employ 260 people in the production of aluminum castings and specialty aluminum alloys. We serve the commercial aviation market and manufacture structural castings for the military, as well as components for heavy-duty hybrid powertrains.

The need for improved aluminum alloys that can function at elevated temperatures is important, and our company has been involved in research on the topic since 2003. We considered the use of cerium as an alloy in addition to aluminum since it is the most-abundant and least-costly rare-earth element and theoretically had the potential for high-temperature strengthening. Cerium also offers a potential solution to the rare-earth supply issue since cerium oxides and carbonates are the primary minerals in many rare-earth deposits, particularly those available in the United States, as in the Mountain Pass mine in California.

However, much of it is returned to the ground as waste. The development of a substantial use of cerium changes the economics of rare-earth production by the beneficial uses of byproduct, thereby lowering the cost of heavy rare-earths used for magnets and electronics such as dysprosium and neodymium. In discussion with Critical Materials Institute representatives at Oak Ridge National Laboratory, it was determined that this expanded use of cerium would serve a role in diversifying the rare-earth supply base, one of the key tasks of the CMI program.

CMI released seed research funding to determine casting characteristics and mechanical properties of aluminum-cerium alloy systems, and it was determined that these systems have excellent castability and superb high-temperature properties, higher even than the aluminum-scandium alloys that we had previously developed. Our company continued to develop the aluminum cerium system with internal funding and with the assistance of national laboratory resources provided in part by CMI. The results were published and presented. The casting purchasing community took notice particularly after the alloy system won an R&D 100 Award in 2017. Eck licensed the technology and continued its development.

Materials development is always a complex enterprise. Potential customers look at the data, request samples, do initial evaluation, and look for attributes of the material that had not been tested or had not been considered in the original development. Commercialization requires ongoing research to make a product in volume that meets all the customer's requirements at a cost that they can afford.

We are working with 5 different Fortune 100 manufacturing companies to deploy the alloy in key products for their organizations. These efforts, industrial scale-up at our company, extensive product testing by the original equipment manufacturers, and continued research to meet product-specific needs and reduce cost are enabling successful development of aluminum-cerium alloys.

We have started on a new phase of research that bypasses the need to produce metallic cerium to alloy with aluminum. We have demonstrated that at laboratory scale. We can alloy aluminum with cerium through direct reduction of the cerium oxide or carbonate at a significant savings in energy and cost. This would eliminate the foreign supply chain completely for this element. As we scale this technology, we expect to be able to produce aluminum-cerium alloys at the same cost as conventional aluminum alloys. Good research can make unexpected advances. We set out to produce and alloy resistant to elevated temperatures, and we were able to do that. In addition, the alloy is remarkably corrosion-resistant, saves energy, and can easily be used in additive manufacturing.

Our success to date has been based upon several factors: The extraordinary team of researchers that have been assembled by CMI, very strong industrial participation; and a willingness to continue to support research that gets over the rough spots as our commercialization proceeds.

Thank you for giving me the opportunity to address you today and to show my support for additional critical materials research funding. Thank you.

[The prepared statement of Mr. Weiss follows:]

Testimony of

David Weiss

VP Engineering/R&D

Eck Industries, Inc

Manitowoc, WI 54220

Before the

Subcommittee on Energy

of the

Committee on Science, Space, and Technology

U.S. House of Representatives

Research and Innovation to Address the Critical Materials Challenge

December 10, 2019

Chairman Lamb, Ranking Member Weber, and Members of the Subcommittee, thank you for giving me the opportunity to appear before you today. My name is David Weiss and I am VP of Engineering and R&D for Eck Industries, Inc., located in Manitowoc, Wi. We employ 260 people in the production of aluminum castings and specialty aluminum alloys. We serve the commercial aviation market and manufacture structural castings for the military, as well as components for heavy duty hybrid powertrains.

Aluminum alloys rapidly loose strength when used at elevated temperatures (about 310° Fahrenheit or 155° Celsius). Important industrial sectors, aerospace companies, and the military require lightweight alloy castings that can operate in temperature ranges of 250-300° Celsius. Current needs in this temperature range are often being satisfied using titanium alloy castings, which are heavier and significantly more costly than aluminum alloy castings. Also, the energy requirements for production are significantly higher. The replacement of titanium alloys with aluminum alloys can reduce the overall energy consumed in the manufacture of products by 532 million BTU's per ton of material.

Because of the importance of high temperature light weight alloys Eck Industries was funded through the U.S. Department of Energy under Award No. DE-FC36-04GO14230 to develop such alloys using scandium and ceramic particles during the years 2004-2013. While the project was successful technically, the rare earth crisis of 2009-2011 made the solution unaffordable. The need for improved aluminum alloys continued to expand and Eck Industries suggested the use of cerium as a possible scandium replacement to the Critical Materials Institute (CMI) in 2015.

Cerium offered a potential solution to the rare earth supply issue, since cerium oxides and carbonates are the primary minerals in many rare earth deposits, particularly those available in the United States such as at the Mountain Pass mine in California. However, much of it is returned to the ground as waste. The development of a substantial use of cerium changes the economics of rare earth production by the beneficial use of a by-product, thereby lowering the cost of the heavy rare earths used for magnets and electronics such as dysprosium and neodymium. In discussion with CMI representatives at Oak Ridge National Laboratory, it was determined that this use of cerium would serve a role in diversifying the rare earth supply base, one of the key tasks of the CMI program.

CMI released seed research funding to determine casting characteristics and mechanical properties of Aluminum-Cerium (Al-Ce) alloy systems and it was determined that these alloy systems have excellent castability and superb high temperature properties, higher even than the Al-Sc alloys that we had previously developed. Our company continued to develop the Al-Ce system with internal funding and with the assistance of national laboratory resources provided in part by CMI. These results were published and presented. The casting purchasing community took notice, particularly after the alloy system won an R&D 100 Award in 2017. Eck licensed the technology and continued the development.

Materials development is always a complex enterprise. Potential customers look at the data, request samples, do initial evaluation and look for attributes of the material that have not been tested for or had not been considered in the original development. Commercialization requires ongoing research to make a product in volume, that meets all the customer's requirements at a cost that they can afford. We have some small customers for the material now who are early adopters and less price sensitive. We are also working with five different Fortune 100 manufacturing companies to deploy the alloy in key products for their organizations. These efforts -- industrial scale up at our company, extensive product testing by the original equipment manufacturers, and continued research to meet product-specific needs and reduced costs -- will enable successful deployment of Al-Ce alloys.

In addition to the ongoing work in cast products, we are working with CMI on the development of Al-Ce powders for additive manufacturing and powdered metal manufacturing. With customer support we have initiated a project on the blending of Al-Ce powders with silicon carbide for wear and corrosion-resistant surfaces. One of the key and unexpected findings of our joint research efforts has been the extraordinary corrosion performance of these alloys. A shipbuilder for the Navy is now testing an alloy that contains enough cerium to prevent corrosion sensitization of common marine alloys.

We have started on a new phase of research that bypasses the need to produce metallic cerium. We have demonstrated that, at laboratory scale, we can alloy aluminum with cerium through direct reduction of the cerium oxide or carbonate at a significant savings in energy and cost. As we scale this technology, we expect to be able to produce Al-Ce alloys at the same cost as conventional aluminum alloys.

Good research projects can make unexpected advances. We set out to produce an alloy resistant to elevated temperatures. We were able to do that. In addition the alloy is remarkably corrosion resistant, saves energy, and can easily be used in additive manufacturing. Our success to date has been based on several factors -- the extraordinary team of researchers that has been assembled by CMI, very strong industrial participation and a willingness to continue to support research that gets over the rough spots as our commercialization proceeds.

Thank you for giving me the opportunity to address you today.

Mr. David Weiss, vice president of engineering and R&D for Eck Industries, Inc., is responsible for development and application of high performance alloys and casting concepts for the foundry and their customers. Weiss has authored over 70 papers on the processing and application of aluminum, metal matrix composite and magnesium castings and authored or co-authored a dozen papers on the Al-Ce alloy system. He has won numerous industry awards including the John A. Penton Gold Medal from the American Foundry Society for pioneering work in the premium aluminum casting industry.

Chairman LAMB. Thank you, Mr. Weiss. Dr. Handwerker.

TESTIMONY OF DR. CAROL HANDWERKER, REINHARDT SCHUHMANN, JR. PROFESSOR, MATERIALS ENGINEERING AND ENVIRONMENTAL AND ECOLOGICAL ENGINEERING, PURDUE UNIVERSITY

Dr. HANDWERKER. Chairman Lamb, Ranking Member Weber, and Members of the Subcommittee, thank you for the opportunity to discuss the importance of research, development, and demonstration to the critical materials challenge and how we can create a workforce capable of ensuring the future supply of critical materials for the Nation.

I'm Carol Handwerker, Schuhmann Professor of Materials Engineering at Purdue University, and the program lead for recycling and reuse in the DOE Critical Materials Institute. Before joining Purdue, I was at NIST for 21 years, most recently serving as Chief of the Metallurgy Division. Both at NIST and Purdue, I've led industry-government-university partnerships to deliver science to solve national problems that industry could and did adopt.

The Critical Materials Institute is a model for how H.R. 4481 might succeed. Drawing on 4 government labs, 9 universities, and 15 companies, it's managed as a single unified organization setting joint priorities to ensure critical materials supplies by connecting basic science with technology, while also developing new researchers and leaders for the future.

CMI shares H.R. 4481's goal, "to assure the long-term, secure, and sustainable supply of energy-critical materials sufficient to satisfy the national security, economic well-being, and industrial production needs of the United States."

In CMI we use four key strategies to deliver meaningful impact from early stage research. The first is identifying the most important challenges and the most effective solutions across the full range of possibilities. The second is collaborating closely with industry from concept stage onward to build solutions that industries can use. The third is delivering quantified economic, logistical, and environmental analyses, and fourth is building teams of the world's foremost researchers to overcome scientific barriers.

Every CMI research deliverable fits into a supply chain with the necessary links to industry. One example is the project for value recovery from hard disk drives, which are data storage workhouses of the cloud and the second-largest use of rare-earth magnets in the global economy. Billions of hard disks are in use across the United States, and tens of millions of them are shredded each year to destroy the sensitive information that they contain. When that happens, the rare-earth elements are lost.

CMI, Seagate, Purdue, and the International Electronics Manufacturing Initiative, known as iNEMI, have forged a project team from organizations that, together, can form a complete supply chain to recover viable quantities of rare-earths from the magnets in scrapped hard drives. The iNEMI consortium membership provides industrial skills and expertise that are complementary to CMI's research capabilities. The 15 organizations on the hard disk drive recovery team include Seagate, Google, Microsoft, and Cisco, as well as a CMI National labs, Purdue, Momentum Technologies, and Urban Mining Company. The project has identified five key approaches to a circular economy for our disk drives with multiple pathways enabled by CMI's fundamental research.

There is a simple key to CMI's most successful projects. We understand that a chain does not exist without all its links in place, and we cannot sensibly build any single link if it is not properly connected to its neighbors. Early career researchers at CMI developed scientific skills and knowledge like any of their peers, but they also see firsthand how seamless collaboration allows great science to emerge from industrial problems. This inspires them to carry forward in this area, and it is one of the hallmarks of CMI.

CMI accelerates technology adoption and bridges the valley of death. It's the place, the so-called, "valley of death," where technologies too often die in the transition from early stage R&D to commercialization. Operating with a sense of urgency from the outset, CMI has developed a focused strategy and applied it to a broadening set of energy-critical materials, translating world-class science into commercialized solutions in as little as 3 years.

Creating a robust supply of energy-critical elements and products for the United States through H.R. 4481's program of research, development, demonstration, and commercial application will enable economic well-being and industrial vitality for the country to continue. CMI has built great capabilities, research teams, and expertise that are consistent with this goal and are ready to be applied to this effort.

[The prepared statement of Dr. Handwerker follows:]

Testimony of

Carol A. Handwerker
Reinhardt Schuhmann, Jr. Professor of Materials Engineering &
Environmental and Ecological Engineering,
Purdue University
West Lafayette, IN

Before the
Committee on Science, Space, and Technology
Subcommittee on Energy
of the U.S. House of Representatives

On
Research and Innovation to Address the Critical Materials Challenge

December 10, 2019

Chairman Lamb, Ranking Member Weber, and Members of the Subcommittee, thank you for the opportunity to discuss with you today the importance of research and innovation in addressing the critical materials challenge, particularly in the context of H.R. 4481, and on the impact of such R&D in creating innovative scientists and engineers capable of ensuring an adequate supply of critical materials, now and in the future. I am Carol Handwerker, the Reinhardt Schuhmann, Jr. Professor of Materials Engineering and Environmental and Ecological Engineering at Purdue University. I am also the Program Lead for Recycling and Reuse in the DOE Critical Materials Institute. Before joining Purdue in 2005, I was at NIST for 21 years, most recently serving for nine years as Chief of the NIST Metallurgy Division where I led measurement programs for improving the manufacturing and performance of electronic, magnetic, photonic, and structural materials vital to industries across the United States. At both NIST and Purdue, I've led industry-government-university partnerships focused on solving significant industry-wide problems by translating fundamental science discoveries into new materials and technologies that industries could and did adopt.

From my vantage point, having been part of and led multi-stakeholder teams to solve significant industry-wide problems, I believe that the Critical Materials Institute is a successful model for H.R. 4481. The Critical Materials Institute has demonstrated how multi-disciplinary, multi-organization teams of innovative scientists and engineers can work together to create new technologies and supply chains for critical materials. The Critical Materials Institute, with its 4 National Laboratories, 9 universities, and 15 industrial partners, is organized, managed, and operated as a single, unified organization, setting priorities and working together on early stage R&D designed to solve the U.S. critical materials problems. The mission of CMI is echoed in the goal of H.R. 4481, "to assure the long term, secure, and sustainable supply of energy critical elements sufficient to satisfy the national security, economic well-being, and industrial production needs of the United States." Four key operating strategies of CMI are designed to accelerate early stage R&D into meaningful impact on the supply of energy critical materials: (1) identifying the most important challenges and developing effective solutions to them by marshalling the most capable research teams; (2) close collaboration with industry at the earliest possible R&D stage, even at the concept stage (TRL-1), (3) enabling new technologies that meet industry needs, explicitly quantifying economics, logistics, and environmental impact at the earliest possible stage, and (4) enlisting the help of world-leading innovative researchers and research tools within and beyond CMI to overcome roadblocks.

Every CMI technology is designed to fit into a supply chain, with industrial links at both ends. Working directly with industry partners at the earliest stage means that CMI researchers understand the quantitative characteristics of feedstocks coming into the CMI technology, the quantitative requirements for an economically viable product enabled by the CMI technology, and the economics of competing technologies, including the status quo with or without alternative sources, materials, technologies or critical materials recycling. One example from the CMI recycling and reuse research portfolio is the electrochemical recovery of Li, Co, Mn, Ni, and graphite from shredded, mixed composition Li-ion batteries. Partnerships with large-scale Li-ion battery recyclers enabled CMI R&D to be performed not on simulated shredded waste as feedstock, but on feedstock from existing commercial processes that do not currently capture all the critical materials. Techno-economic and environmental impact analyses identify bottlenecks, driving early-stage research to eliminate these potential technological barriers to economic viability and sustainability. Finally, open discussions of scientific roadblocks for individual projects across CMI have led to CMI researchers outside the projects seamlessly working with those project teams to overcome the roadblocks. These strategies are helping to create functioning, sustainable supply chains: a chain cannot exist without all the links in place and you cannot build one link without working with its neighbors.

I am pleased to be here today representing Purdue University, a public land-grant university with 44,500 undergrad and grad students, 2/3 of which are in STEM disciplines. Purdue is one of the major engineering universities in the United States: 5th in the number of undergraduate engineering degrees awarded at 1771 in 2019; 5th in the number of women awarded undergraduate engineering degrees at 412 in 2019; and 5th in doctoral engineering degrees awarded at 280 in 2019. One of Purdue's areas of expertise is advanced manufacturing, from developing new materials and processes for additive manufacturing to creating systems-level models and scenario analyses for value chains. A major contribution of Purdue faculty, graduate students, and postdocs to CMI has been their creation of tools for researchers across CMI to do preliminary self-assessments of both the economics and the environmental impacts of their early-stage technologies. These are cornerstones of advanced manufacturing research. Purdue researchers then help them refine their analyses, then identify and eliminate the economic and environmental hotspots that might limit industry adoption. Using these tools and analyses caused a cultural shift during the first five years of CMI. This has translated into further acceleration of technology development and greater industry involvement since the beginning of the sixth year. In terms of workforce development, through their experiences in multi-disciplinary CMI teams, CMI graduate students and post-docs at Purdue and across CMI have developed not only the discipline-based knowledge, skills, and abilities needed as "technically trained personnel necessary for energy critical elements research, development, and industrial production" but also have learned how to engage with industry during early-stage R&D to maximize the likelihood that the technologies they create will be economically viable and environmentally sustainable.

Finally, the CMI strategies for accelerating technology development for energy critical materials are working to bridge the "valley of death", where technologies die during the transition from early stage R&D (TRL 1-4) to pilot scale demonstrations, scale-up, and finally to commercialization. The "valley of death" occurs for many different reasons, as discussed in the 2004 National Academy of Engineering Report, **Accelerating Technology Transition: Bridging the Valley of Death for Materials and Processes in Defense Systems**, which I co-authored. What is impressive about CMI as an organization is that its characteristics – how it is organized and manages itself, and how the researchers across CMI work on common high level goals – map almost exactly into the recommendations of the NAE Report.

A good example of how CMI is forging strong links in the supply chain is the industry-government- academia-NGO project for Value Recovery from Hard Disk Drives. Hard disk drives are one of the most widespread uses of rare earth magnets, with over 400 million of hard drives sold per year and billions still in service. Hard drives are the work horses of Cloud and data center storage, with tens of millions of hard drives retired from service each year by the hyperscale data centers alone. Through the leadership of CMI and team members Seagate and Purdue, the International Electronics Manufacturing Initiative, a consortium of more than 90 manufacturers, suppliers, industry associations, consortia, government agencies, research institutes and universities, brought together a team of individuals and organizations who not only represented the full supply chain for value recovery for HDDs, but also the wide range of expertise and creative thinking needed to address this multi-dimensional challenge of value recovery from HDDs. The primary focus of the project was to demonstrate an economically viable, environmentally sustainable circular economy for hard drives, with multiple pathways enabled by CMI research on for hard drive disassembly, magnet reuse, and recovery of rare earth oxides and metals. The electronics industry stakeholders (CMI team members and affiliates marked with *) who participated in the NEMI project included: Ames Laboratory*, Cascade Asset Management, Cisco, Critical Materials Institute*, Echo Environmental, Geodis, Google, Green Electronics Council, Idaho National Laboratory*, Microsoft, Momentum Technologies*, Oak Ridge National Laboratory*, Purdue University*, Rifer Environmental, Seagate Technology*, Teleplan, University of Arizona*, and Urban Mining Company. Based on the successful demonstration of five new pathways for value recovery, discussions of larger scale collaborations and demonstration projects are underway with multiple supply chain partners.

CMI is not simply a research program with a collection of projects focused generically on critical materials or local research interests and capabilities. CMI undertakes world-class research on specific opportunities for, and challenges to materials supply chains. It provides a comprehensive strategy for accelerating technology development to create a long term, secure, and sustainable supply chain for energy critical elements and products for the United States. Operating with a sense of urgency from the outset, CMI has used this strategy to produce striking results in a very short period of time. While government-funded R&D usually takes at least 20 years to move from discovery in the lab to success in the marketplace, CMI inventions have been adopted by industry in as little as three years from the beginning of research. This is important to keep in mind as the list of energy critical materials continues to grow, with equally difficult scientific, technological, and supply chain challenges that must be quickly overcome. The federal government's commitment to creating a supply of energy critical elements and products for the United States through the H.R. 4481 "program of research, development, demonstration, and commercial application" will be needed to have a hope of mitigating the increasing risks to national security, economic well-being, and industrial production.

Carol A. Handwerker

Carol Handwerker is the Reinhardt Schuhmann, Jr. Professor of Materials Engineering, and Environmental and Ecological Engineering at Purdue University, West Lafayette.
Prior to joining Purdue in 2005 she served as the Chief of the NIST Metallurgy Division for 9 years and a NIST group leader and metallurgist for the prior 12 years. At NIST she led measurement programs focused on improving the manufacturing and performance of electronic, magnetic, photonic, and structural materials used in a wide variety of industries. Her research areas include:

- developing innovative processing strategies and technologies for next-generation microelectronics, solar cells, and printed electronics,
- integrating sustainability in the design of new materials, processes, and products.
- identifying and implementing strategies to move R&D into manufacturing and commercialization, using roadmapping, techno-economic analysis, and formation of robust supply chains.

In all of these areas, she works closely with different industry sectors and their stakeholders to transform R&D into practice. For example, with iNEMI (the International Electronics Manufacturing Initiative), an industry consortium of over 90 companies and organizations, she helped lead the US electronics industry in the world-wide conversion to high-volume manufacturing with Pb-free solders. She is a member of the iNEMI Environmental Leadership Steering Committee, along with Intel, Dell, Nokia, Lenovo, and others, and co-led an innovative demonstration project on Value Recovery from End-of-Life Hard Disk Drives, with Seagate, Google, Microsoft, and Cisco as active team members. Prof. Handwerker leads the DoE Critical Materials Institute Focus Area in Recycling and Reuse, focused on accelerating technology transition of early stage CMI research into practice. She holds a B.A. in art history from Wellesley College, and S.B., S.M., and Sc.D degrees in materials science and engineering from MIT.

Chairman LAMB. Thank you, Dr. Handwerker.

We will begin with 5-minute rounds of questions. I recognize myself for 5 minutes.

Dr. Schwartz, I'd like to start with you. Thank you for giving so much attention to NETL and their program of rare-earth research. You mentioned in your testimony the three domestic pilot-scale operations that they have going on. Would you mind just saying a little bit more about what those are and where they operate and exactly kind of what they're producing today?

Dr. SCHWARTZ. I don't have all the details on that. I can get them for you. We'd be happy to do that. Much of the work has been done I believe in collaboration with universities, particularly University of Kentucky, where that team is trying to understand the chemistry and the science and the technologies of extracting those rare-earth elements, which essentially start with maybe 300 parts per million of concentration, so in many ways trying to extract very low abundant elements from whatever products.

In many cases, though, for example, the acid mine drainage, those rare-earth elements are, relatively speaking, a chemically easy way of extracting. So the development of the science and the technology and ultimately the pilot-scale project is aimed to extract those elements as efficiently as possible. Again, I don't have all the details, but I'd be happy to work with my NETL colleagues to provide that specific answer.

Chairman LAMB. That's OK. Thank you. With the acid mine drainage extraction, I noticed also in your written testimony you characterize that as easy. How would you explain, then, kind of what barriers remain for the actual commercial application of that? You know, a comparison is in Pennsylvania where there are companies that make a profit burning waste coal. You know, they've figured out a way to convert that into something that can still produce energy. If it's easy to extract minerals from those same coal piles, what does the future look like in terms of how we might actually get to commercialization?

Dr. SCHWARTZ. Well, I will say there are two issues. Both of them deal with the economics. One is being able to develop the large-scale processing plant, and the second would be how do you move that processing plant to the location where the acid mine drainage is located or other sources are located. So that may be incompatible, so then the challenge would be how do you develop somewhat mobile units that could move from one acid mine drainage location to another to another to another. So the bottom line I believe, as with most things, it's economics. How do you do this economically, either to develop the chemistry processing but then also to locate that chemical processing facility or to be able to move it where it needs to be.

Chairman LAMB. Thank you. That's actually the same challenge with people who burn waste coal is the transportation cost is almost everything to them. Thank you.

Dr. SCHWARTZ. As with recycling as well.

Chairman LAMB. Yes. Mr. Weiss, first of all, thank you for being here and for sharing that story. It's such a clear example of success. I was trying to just understand the timeline. Did you first get the Department of Energy grant in 2004? Is that right?

Mr. WEISS. We began work with CMI approximately 5 years ago.

Chairman LAMB. OK.

Mr. WEISS. So we had done some earlier work on scandium-containing alloys for high-temperature applications before that.

Chairman LAMB. I see. So that was kind of a different project.

Mr. WEISS. It's a different project, correct.

Chairman LAMB. I was sort of just trying to understand the length of time from when you started working on the aluminum-cerium alloys, with DOE support, to sort of commercialization, what that looked like.

Mr. WEISS. Well it's been about 4 years.

Chairman LAMB. Four years, OK.

Mr. WEISS. We had our earliest customer about 2 years in—it was an early adopter customer who really was interested in the performance of the material and weren't required to go through a lot of extensive testing. Working with much larger customers, Fortune 100 customers, the testing regime is much, much longer, as you can imagine.

Chairman LAMB. And do you think you would have been able to accomplish this without Federal support?

Mr. WEISS. Absolutely not. We can make the castings. We know how to make the castings. We know how to alloy material, but understanding what you have, doing the microstructural analysis, understanding the mechanisms in play in order to understand the strengthening of the alloy, we don't have those capabilities at all. And the national labs have them in abundance.

Chairman LAMB. Thank you. Mr. Weber, you're recognized for 5 minutes.

Mr. WEBER. Thank you. I don't know where to start. This is great.

Dr. Hayes, I owned an air-conditioning company for 35 years, so all this stuff about energy transfer and freon and so on and so forth is really interesting to me. You said that you used helium, and of course your budget was flat. That didn't escape me, and helium has gone up 400 percent in your testimony. And then you also said you had to decommission magnets and that they have to be filled every three to four weeks.

Dr. HAYES. Yes, that's correct.

Mr. WEBER. So magnets use helium?

Dr. HAYES. Indeed. So they're using helium to achieve what's called a superconducting state to create the magnetic field.

Mr. WEBER. OK. Is that very low cryogenic temperatures?

Dr. HAYES. Yes, it's 4 Kelvin, a very low temperature, about the temperature of outer space as an equivalent.

Mr. WEBER. Put that in Fahrenheit for me, will you.

Dr. HAYES. In my written testimony I believe I have it. It's minus 450, minus 460. I can get you the exact number.

Mr. WEBER. I keep talking about inches and yards, and my keep kids keep telling me have to get into the metric system. They said get in the metric system, Dad. I said I'll get there inch by inch. Just don't push it.

Dr. HAYES. Minus 452 is the exact.

Mr. WEBER. Minus 452. OK. Well, freon freezes and minus four something. I took that class 30-something years ago. You said helium will get the coldest that we have. What's the second-coldest?

Dr. HAYES. Good question. I believe hydrogen, perhaps hydrogen.

Mr. WEBER. Is it hydrogen?

Dr. HAYES. Yes.

Mr. WEBER. OK.

Dr. HAYES. The molecule hydrogen.

Mr. WEBER. OK. And I thought you said that helium evaporates as we use it.

Dr. HAYES. It does.

Mr. WEBER. OK. But then you also said we want to try to collect it.

Dr. HAYES. Yes.

Mr. WEBER. Did I misunderstand that?

Dr. HAYES. No. So what I meant is two things. One is because it's inert, as it evaporates, it escapes the atmosphere. It is, if I'm not mistaken, one of the only elements to do so. So whatever we have here on the Earth that we release is gone. So by——

Mr. WEBER. It escapes the atmosphere——

Dr. HAYES. Yes.

Mr. WEBER [continuing]. As it goes into outer space?

Dr. HAYES. It goes into outer space.

Mr. WEBER. And now you know why outer space is so cold.

Dr. HAYES. That's very funny.

Mr. WEBER. Yes.

Dr. HAYES. So by recycling it and keeping it contained, then we can continue to reuse it. Let me give you a quick analogy.

Mr. WEBER. But how do you recycle it, Doctor, if, when you use it, you use it up?

Dr. HAYES. So imagine the radiator of your car. It's like a cooling fluid that can be circulated around and around. Sure, a little bit leaks out and it must be topped off, but——

Mr. WEBER. OK.

Dr. HAYES [continuing]. That kind of recycling.

Mr. WEBER. But you want a closed loop. Is that helium pressurized? If it's at low pressure, it's a liquid, right?

Dr. HAYES. It's a closed loop——

Mr. WEBER. It's a closed loop.

Dr. HAYES [continuing]. And all we have to do is recapture the gas, compress it again into a liquid, and then reuse it around and around.

Mr. WEBER. So how do you recapture that gas?

Dr. HAYES. Through piping generally and through large bags that can have space to hold all that gas.

Mr. WEBER. OK. But you wouldn't literally expect for that to be in the radiator of your car because it's too cost-prohibitive and too expensive?

Dr. HAYES. Indeed, but if we could co-locate helium using equipment and several users——

Mr. WEBER. OK.

Dr. HAYES [continuing]. Could all use of such a system.

Mr. WEBER. You keep calling helium inert. For the audience, inert, i-n-e-r-t, not a nerd. Yes, I'm the nerd here because all this stuff fascinates me. So thank you for that.

Mr. Weiss, I'm going to jump over to you. You said the need for elevated temperature for aluminum alloys—again, I was in the air-conditioning business. We get a lot of welding, copper, and there's a lot of braising and stuff that goes on. And you said you are considering cerium and dysprosium. Was that the other one?

Mr. WEISS. Well, cerium is the element that we are using.

Mr. WEBER. OK.

Mr. WEISS. Dysprosium is too expensive to use.

Mr. WEBER. Oh, I got you.

Mr. WEISS. Right.

Mr. WEBER. So the need for elevated temps, so when you do a high-temp alloy aluminum casting, what kind of temperature can you expect to encounter? Is it 200 degrees? Is it 1,200 degrees? Again, I'm Fahrenheit.

Mr. WEISS. So in Fahrenheit most aluminum alloys lose all of their strength around 300 degrees Fahrenheit. And so what we are doing and what we've indeed demonstrated on these alloys is reasonable mechanical properties all the way up to 600 degrees Fahrenheit.

Mr. WEBER. What application would that apply to? Who would use that?

Mr. WEISS. There's a couple things. The turbochargers, which are getting hotter and hotter as you try to improve engine efficiencies; things like cylinder heads, as you increase the power density, the temperature goes up. Those would be two of the major potential manufacturers.

Mr. WEBER. Do you sell to the automotive market for like engine blocks for example?

Mr. WEISS. We do right now, not in aluminum-cerium alloys yet, but they are being tested by them.

Mr. WEBER. So is there a higher—and again, I'm just the technical nerd that I am, is that for diesel engines? Is that higher than gasoline engines?

Mr. WEISS. Yes, it is. And most of the work that we're doing is for diesel engines currently.

Mr. WEBER. OK. Well, I've got other questions and, Mr. Chairman, I'm going to yield back.

Chairman LAMB. I recognize Chairwoman Johnson for 5 minutes.

Chairwoman JOHNSON. Thank you very much, Mr. Chairman, and thanks to all of our witnesses who have come.

I'm a little concerned about some of the reactions. Dr. Schwartz, in your testimony you discuss both the short-term and the long-term risks of critical materials supply chains. Could you discuss the differences between the two, and the possible short- and long-term solutions available, or their approaches?

Dr. SCHWARTZ. Short-term, most of those supply risks are political or geopolitical in nature, meaning—and we can use the example from 2010 of the rare-earth crisis where over the previous 30-some years where in the 1960s the U.S. used to be the number-one producer of rare-earth oxides in the world at the Mountain Pass mine. Over that subsequent 30 years, most of the world's mining, processing, and fabrication of rare-earth elements came out of China. Then there was a price spike, which led to increases in prices up to maybe 50 times for certain elements. That is the type of short-term geopolitical risk that could occur in rare-earths, as it did previously, or in other materials. Currently lithium is not produced in significant quantities here in the U.S.

Long-term, that geopolitical risk remains. If we become, as a country, more reliant on importing materials like lithium for batteries or whatever that next critical material could be, that is one source of the long-term risk. The other source of long-term risk is if we, as a community, discover the next great functional material, whether it is for quantum computing or caloric cooling, could be any of that. If that demand for that new technology outweighs current production either in the United States or in the world, that also sets up for long-term critical materials risk.

Chairwoman JOHNSON. Well, how do you think that the research community has responded to this reaction from China, especially in alleviating some of these risks?

Dr. SCHWARTZ. So the United States, Japan, European Union have a yearly get together, the Trilateral Meeting to discuss critical materials and the response to those critical materials needs. Japan has its approach. The European Union has its approach. The United States has focused its resources on the Office of Fossil Energy, National Energy Technology Laboratory program to extract rare-earths from a known resource we have here in the U.S., and that is coal and coal byproducts. And that team is making excellent progress. They are now to the point where they believe they can make salable, low-cost, high-purity rare-earth oxides.

The second major program, Critical Materials Institute has made significant progress across all of the supply chains from diversifying the supply, improving reuse and recycling, and in developing substitutes. An example that I put in the written testimony is about replacing some of the more rare rare-earth phosphors in fluorescent lamps. Fluorescent lamps use a tri phosphor red, green, and blue. The red and the blue—and the green in particular use those more expensive heavy rare-earth elements. The CMI team created options for that lighting industry that required no rare-earths as a replacement for or a substitute for the red phosphor and only 10 percent of the rare-earths required for the green phosphor. So short-term the team is making significant progress in all three of those areas. Use less or make more.

Going forward, it is that combination, it is that teaming of all the expertise. It's not just doing science. It's not just creating the next material, but it's understanding how that research could potentially improve the supply chains going all the way back to the techno-economic analysis, doing the road-mapping, talking to U.S. industries. What is most important now and then in the future? And a coordinated effort like I think is being done—there's a lot more to do, but that coordinated effort moves us along that path toward addressing those critical materials challenges. It's really that critical material framework that has been put in place over the last 5 years that is now positioned to accelerate the development of options for the supply chain risks.

Chairwoman JOHNSON. Thank you very much. My time is expired.

Chairman LAMB. I recognize Dr. Baird for 5 minutes.

Mr. BAIRD. Thank you, Mr. Chairman. And thank you, witnesses, for being here. We do appreciate all the information you bring us in terms of the latest technology regarding these rare-earth elements and Dr. Handwerker, I'm going to start with you. I must tell you that I'm always pleased to see my alma mater involved in the cutting-edge technologies, so thank you for being here.

My question deals with the comments you made in your prepared testimony. You state that while government-funded R&D usually takes at least 20 years to move from discovery in the lab to success in the marketplace, then DOE's Critical Materials Institute or CMI inventions have been adopted by industry in as little as, say, three years. In your opinion what unique role do CMI's academic partners like Purdue University play in this success? And then what recommendations do you have for other academic institutions who may want to partner with the DOE energy innovation program?

Dr. HANDWERKER. Thank you. First of all, boiler up.

Mr. BAIRD. Boiler up.

Dr. HANDWERKER. So at Purdue University one of our hallmarks is advanced manufacturing, and so much of what we do in critical materials is really focused in advanced manufacturing. Advanced mining is really part of the manufacturing infrastructure of the Nation.

So at Purdue one of our key contributions to the Critical Materials Institute has been developing tools to do those economic analyses you were talking about, the logistics analyses that are so important in determining whether a technology, whether it be mining or recycling or reuse, are going to be profitable.

We've created these tools that we have taught all across the Critical Materials Institute, we've taught the different project leads all the way down to even undergraduates how to do these economic analyses as they're developing these key technologies because if you look at the scientific literature and you want to find, OK, how do you get rare-earth materials out of magnets, there are many papers associated with that. There are many papers on the topic. The issue, though, is it can't be done economically with low environmental impact and in a way that actually gets the material, for example, in collection.

So one of the things that we've been able to contribute are these economic analyses, lifecycle assessments, and also scenario analyses, which are also called out in H.R. 4481. It is so important to see, all right, how do we mitigate the risks for our critical materials?

Mr. BAIRD. Thank you. Do any of the other witnesses have an opinion about what areas of fundamental research would provide the highest return on investment? So, Dr. Schwartz, start with you.

Dr. SCHWARTZ. One of the biggest bottlenecks right now is being able to separate the rare-earths from one another and then to take those separated rare-earth oxides and create metal out of it. That is not the environmentally cleanest process out there. So although the world, although Critical Materials Institute and researchers around the country are making progress understanding that separation process, being able to take one rare-earth oxide out of the collection of rare-earth oxides, as Dr. Handwerker pointed out, it's not yet economical. So fundamental and early stage research into those separation processes are I still think one of the keys. Critical Materials Institute is doing some but really not enough work in taking those rare-earth oxides and converting into metal because that's really in most cases the starting point for making materials to be put into systems, to be put into products that are needed for U.S. energy security, national security, and other things.

So I think continued focus on that processing required to separate the rare-earth oxides from each other, make the metal, and then there are huge opportunities not only for critical materials but in the areas of recycling, recycling of the hard disk drives, which Carol pointed out, the recycling of lithium in batteries, in cobalt, in magnets from the first generation of hybrid electric vehicles, for example. Recycling science has been lagging behind for lots of reasons, including economics, but the science needs to be done to do that to develop processes to extract those materials economically.

Mr. BAIRD. Thank you. And, Mr. Chairman, could we have the other two? I'm over my limit.

Chairman LAMB. Sure. I think they can speak quickly.

Mr. BAIRD. Thank you. Go ahead.

Dr. HAYES. I'll be brief just to say that within the areas of magnet technology, we heard about neodymium from a couple of speakers. This is not part of my written testimony, but there are efforts at the National High Magnetic Field Laboratory to develop superconducting magnets that are based on high-temperature superconductors. They would use different elements, they would have different designs, and we might be able to escape even the use of liquid helium. So that's a new direction that could be pursued but is not maybe heavily funded at the moment. But those designs exist.

Mr. WEISS. So in response to, you know, how students play a role and how academic institutions play a role, it is interesting to me that having had demonstrated some success in the use of cerium, for example, in materials, there's probably four or five masters students now outside of the CMI envelope that have looked at that and are looking at various things that we have not looked at in CMI as far as particular mechanical properties or whatever. And so research gains a certain momentum after a certain point and more and more people get involved, and that's going to be good for everybody all the way around.

Mr. BAIRD. Thank all of you, and I yield back.

Chairman LAMB. Thank you. And I recognize Mr. Foster 5 minutes.

Mr. FOSTER. Thank you, Mr. Chairman, and to our witnesses.

Let's see. I guess I'll start with Dr. Schwartz. How do you deal with the fact that you don't really know 10 or 20 years from now which elements will end up being strategic? You know, we're worrying about lithium, and there's an excellent chance that we'll succeed at battery R&D that looks at divalent chemistries, and it's magnesium which I don't think will ever be strategic—will be the key element in batteries. You know, there are alternative technologies like switched-reluctance motors that may make rare-earth motors irrelevant for many applications.

You know, I think someone mentioned phosphorus for fluorescent bulbs, OK. They're being replaced by LEDs. I'm not sure whether white LEDs—I know they have some kind of wave shifter but I'm not sure that that's a rare-earth wave shifter where they get a blue LED and then use a full spectrum. So how do you deal with that, you know, both in the U.S. and in these international meetings?

Dr. SCHWARTZ. Dr. Foster, that is a great, great question. Like so many things, we have good visibility out to the horizon. We know what is coming up. We know that electric mobility is going to be very significant in this country and across the world. We suspect that quantum information sciences, quantum computing is going to be significant at some point. But we don't have visibility across the horizon, and that's why the development of the framework, the processes, the critical materials framework that allows us to take a look at the problem as early as we can, do that criticality assessment where we are trying to look out at new industries of the future to say this could create a demand for manganese. Manganese could be a great element. Magnesium could be a great element. But until there is a science and technology base, until there are applications beginning to show up, can we say, ah, that could be large. So I think from my perspective it's developing that enduring capability, that critical materials framework that we'll be in a position to address the next critical material as quickly as possible when that material becomes critical.

Mr. FOSTER. And in these international meetings is there some understanding that the countries of the free world are not going to do what the Chinese did to the Japanese not so long ago and, you know, grab them by the neck and try to get concessions on something? Do you think there's a need for some sort of understanding along those lines at least among the free world?

Dr. SCHWARTZ. That's really outside my area of scientific expertise, but I would say yes. Just a few weeks ago Energy Efficiency and Renewable Energy Office, Advanced Manufacturing Office, and the Office of Fossil Energy organized a roundtable and workshop on rare-earths. We had representatives from Canada and from Australia talking about those partnerships that will help protect against a single country dominating a material, dominating a market. So I say yes, there is room for significant discussions to make sure that those partnerships are in place.

Mr. FOSTER. And, Dr. Hayes, I guess as a Member of—probably the Member of Congress that's responsible for venting more helium—I don't think I could count the number of 500-liter helium dewars that experiments I've set up have vented to the atmosphere.

You know, there are a number of approaches you can take here. You mentioned sort of local, like somewhere in the building multiple researchers would have a shared helium recycling facility. There are other approaches, for example, just using closed cryocoolers for these research magnets, which, you know, there are a number of different approaches here.

And in addition, there's a class of helium applications where it's simply used as a nonreactive purge. And that's I think, particularly in a research environment, I think is going to be very hard to figure out how to sensibly, you know, recycle that. In addition, if it gets diluted enormously, then you have to cryogenically separate. I mean, there's a range of applications here. And why is it not best just to let a market price do this to try to figure out which ones of these applications make sense and which don't?

Dr. HAYES. So the types of things that you're talking about require a capital equipment investment that is not necessarily part of the framework for most of us that have equipment from a decade ago, let's say, or further back. So that's the first of the answers. And then why not let a market price account for that? That's outside my area of expertise, too, you know, resource economics. But truly in this era where we have had cheap and abundant helium, we're now in a completely different world and how do researchers respond agiley to that new reality? That's what you're asking. And we need extra money for research for those of us who are subject to those price fluctuations.

Mr. FOSTER. Yes. And also I think you're a little pessimistic on YBCO (yttrium barium copper oxide) and the other high-temperature superconductors. I think a lot of research magnets could be made today with high-temperature superconductors.

Dr. HAYES. I completely agree. All I meant by the statement was just that it is not widely adopted yet. It's not commercially available as a magnet, and it's only in these very specialized centers of excellence that we have in the United States that have really capitalized on that.

Mr. FOSTER. Thank you.

Dr. HAYES. Thank you.

Mr. FOSTER. And, Mr. Chair, if there's an opportunity for a second round of questioning, I'd appreciate it.

Chairman LAMB. Sure thing. Mr. Biggs is recognized for 5 minutes.

Mr. BIGGS. Thank you, Mr. Chairman and Ranking Member Weber. This has been an interesting hearing. Thank you for your presentations, all of you coming today.

Dr. Hayes, I want to just kind of dovetail if I can a little bit on the discussion that was going on because you mentioned the price has gone up I think 450 percent during your career of helium, which indicates to me that either the demand has exceeded the supply or you've had an increasing scarcity. And I'm assuming that it's the latter that's an increasing—maybe it's both, a combination of both. So can you kind of define that for me why the price has gone up?

Dr. HAYES. The price is related to scarcity, as you say indeed.

And again, this is outside my special expertise, so I wouldn't want to attribute it to any one cause, but certainly we have seen increasing demand for helium worldwide. It's used heavily in the electronics industry, for example.

Mr. BIGGS. OK.

Dr. HAYES. So I think that it's both factors.

Mr. BIGGS. OK. And one of the ways to resolve it is both the way Dr. Foster said is finding alternatives to helium and what you've also said is reuse, recovery, and recycling.

Dr. HAYES. Yes.

Mr. BIGGS. So there's a third alternative, and this is the part I know nothing about because I don't know where we find helium. If we we're talking copper and molybdenum, I could tell you about that, but I can't tell you about helium. Are there other markers, I mean, people are exploring, developing, we're talking oil and gas we would know that there's a field, we would be looking at geologic formation. We could kind of accurately—as we explore, we could see how much we're going to have. Tell me about helium. How do we find helium? What are our other markers that go with it? Is it coming with nitrogen? Do we find it with other gases? How does that work?

Dr. HAYES. Currently, we extract helium through the process of extracting natural gas.

Mr. BIGGS. OK.

Dr. HAYES. So it comes along for the ride. It is not in all natural gas deposits. And for it to be economically viable, I understand from others who are in this industry that you need roughly 1 percent of the makeup of that natural gas deposit.

Mr. BIGGS. I see.

Dr. HAYES. And it's because the natural gas is trapped underground by rock formations, and luckily for us, the helium is there as well.

If I may, let me put something into context for you.

Mr. BIGGS. Yes.

Dr. HAYES. A single balloon of helium, a party balloon, if I do a back-of-the-envelope calculation on a pad of paper, the number of gas molecules that are there are coming about because of radioactive decay of uranium and thorium underground. That balloon takes an amount of half a pound of uranium that I could hold in the palm of my hand. It takes it 1 billion years to decay on that order.

Mr. BIGGS. Wow.

Dr. HAYES. So we are constantly making more underground, but it's an atom at a time. So I favor recycling for that reason because we just don't want to let it escape the atmosphere.

Mr. BIGGS. Right. Very good. Thank you. That's very informative. And I'm glad you mentioned uranium because I come from Arizona. And in Arizona we have significant reserves of copper and uranium. And the President and his Administration has protected our national economic security from reliance on foreign supplies of critical minerals, ostensibly including uranium. But we're having a terrible time developing uranium. We're fighting that right now.

The U.S. Geological Survey's list of 35 critical minerals encompasses materials, as you know, for clean energy production, nuclear deterrence, and enabling smartphones, et cetera, around the world. But instead of buying from the domestic uranium mining companies, we are looking to China for uranium right now and other countries. We import almost 99 percent of our uranium. And that makes it really, really a security risk for us, and that's something we should be aware of. And so I think we should be exploring all those options.

And so I'm going to ask each one of you in the brief time I have left, as we've talked about these things, if you can kind of expand and advance the idea of what you use with industry partners, specifically those who might be in the academic world, what do industry partners do with you, and how do they support your efforts and if you can expand on that for me.

Dr. Handwerker, let's start with you and we'll——

Dr. HANDWERKER. Yes. I'll start. I'll start here.

Mr. BIGGS [continuing]. Go this way. OK. Great.

Dr. HANDWERKER. So one of the important parts of working with industry to see whether something could be economical is we delve into the economics in great gory detail to see what it would take to actually be competitive. And without doing that, then, you know, if we fall short, then it's not like horseshoes. You know, it really matters that we have gotten the economics right. And with it the economics challenges come the scientific challenges because it doesn't come for free. It's not like we can just marginally change the science to have these breakthroughs.

So by working with industry really from the very earliest possible steps, then we can see what science that has already been developed that we can't use because it falls short of the economic, the environmental concerns as well. And so that's key. And also knowing in the end that we've done everything we could at the point of handoff at early stage but late enough stage that we've mitigated the risks for the companies because without the companies having those risks mitigated, they're not going to be able to get the capital needed to move forward.

Chairman LAMB. And I'm going to recognize Ms. Stevens now for 5 minutes. We can come back in a second round if there's more to be said on that topic. Thank you.

Ms. STEVENS. Thank you, Mr. Chairman, for this very important hearing on a critical topic with such great expertise here.

I'd like to submit a letter for the record from Umicore. It's a company with operations in my district that is recycling end-of-life electronics and batteries spent in automotive and industrial catalysts and other metals-containing materials that can be recycled.

There's also a company I'd like to highlight who I've spent some time with, SoulBrain, which produces low-moisture and high-purity lithium-ion electrolyte. They are the only electrolyte manufacturer in my district for lithium-ion and the only one in Michigan and one of two in the country. And why the geography is significant is that I represent the country's largest concentration of automotive suppliers, and we're ushering in this electric vehicle wave but with one in Michigan that's responsible for electrolytes. So I think the imperative and the urgency around today's discussion is quite apparent.

Mr. Weiss, your company, it's private, a private company?

Mr. WEISS. That is correct.

Ms. STEVENS. OK. And if you could share, what's your, you know, revenues or profit or valuation?

Mr. WEISS. Yes. So we sell about $50-million worth of castings per year.

Ms. STEVENS. That's great. And you're employing about 260——

Mr. WEISS. Two hundred and sixty people, correct.

Ms. STEVENS. Fabulous. And you're in the Midwest as well——

Mr. WEISS. That's right.

Ms. STEVENS [continuing]. Which we appreciate. And you know, we're talking a lot about the R&D, but I want to talk about the level playing field. And if you could just shine a little bit of light on that from your vantage point, do you feel like we have a level playing field when it comes to these types of materials and our access to these materials?

Mr. WEISS. Well, we clearly don't—I—in my mind. Most of the materials or many of the materials are imported from China.

Ms. STEVENS. Have your payments gone up since you're importing from China?

Mr. WEISS. No.

Ms. STEVENS. What you're paying for them? OK. They've gone down?

Mr. WEISS. They're roughly the same, roughly the same. Yes, I mean, there's an impediment there because, you know, everything from potentially transportation costs, to time, to quality of material, and so on, those are all negatives. And we have the wherewithal to do it in the United States or we're developing the wherewithal to do that all in the United States, and we haven't quite done it yet.

Ms. STEVENS. And what else could it take to help us develop that wherewithal? What else do we need besides the R&D efforts?

Mr. WEISS. Well, I think you need the R&D effort. I think you need customers to help support the work that you're doing, not always buy from the lowest-cost producer, you know, so being in the automotive supply market, we understand that a little bit. And so there's a lot of effort to reduce the cost of materials obviously.

Ms. STEVENS. Right. And there's a demand factor as well. And as my colleague Dr. Foster talked about, the flexibility for the delineation of what is dubbed a strategic material whereas that could change, I think we also need some flexibility in terms of procurement. Wouldn't you agree, Dr. Schwartz, in terms of how we maybe maintain or gain access to these materials and the ways in which we go about them, and the ways in which we incentivize the potential consumer activity within our own markets?

Dr. SCHWARTZ. I do agree with that, Representative Stevens. The United States has plentiful natural resources. We do have rare-earths. We do have lithium supplies. The challenge really is overcoming the economics to compete globally. And I can't speak to what other countries' policies are, but when it comes to mining, mining has environmental challenges. And our challenge as a country is to develop clean, environmentally acceptable mining processes. And to this point that's not yet economical. So it is very challenging for U.S. mining interests to get into that business because it takes so long to get approved for a new mine, because the environmental regulations are what they are. And we as a country haven't yet developed clean mining technologies because there hasn't been a clean mining program out there.

So we have lots of challenges. We have the natural resources here.

We just need to figure out a way technically and regulation-wise to extract those elements so that your companies in Michigan have all the lithium that they need to produce batteries and electrolytes for——

Ms. STEVENS. And so they can compete——

Dr. SCHWARTZ. So they can compete.

Ms. STEVENS. While we're certainly enthusiastic of the legislation on the docket, I am sniffing that there's opportunity for further legislation. But with that, Mr. Chairman, I remain enthusiastic for a second round of questioning and yield back my time.

Chairman LAMB. Thank you, and recognize Mr. McNerney for 5 minutes.

Mr. MCNERNEY. Well, I thank the Chair. And I thank the witnesses this morning.

It's really encouraging to hear some of the successes of the CMI. We created that in part because of concern about China's dominating the market and what we've seen with Japan lately sort of verified that. And they don't seem to have the environmental concerns and regulations that Dr. Schwartz just referred to, and that's a bit of a challenge for us, but I'm sure we can get through it.

The one question I have—is there an opportunity to, Dr. Schwartz or anyone, to obtain critical rare-earth materials through fracking and/or geothermal energy production?

Dr. HANDWERKER. Not as far as I know.

Mr. MCNERNEY. Nobody has a positive answer on that?

Dr. HAYES. Helium does not come through fracking processes either so I'll just say that.

Mr. MCNERNEY. All right. Thanks. Does the difficulty of obtaining rare-earths—and this follows up with Ms. Stevens' questions—give other countries a critical advantage on battery manufacturing? Dr. Schwartz?

Dr. SCHWARTZ. Again, the United States has enough lithium reserves to become a net exporter to the world.

Our challenge is, again, the economics of extracting that lithium and turning it into a product that can be sold on the world market. We have the material. We just have to figure out—again, we have to overcome those barriers to the scientific processes of how do we extract the lithium from geothermal brines, how do we extract the lithium from mine tailings. I think we have that. I think we have developed that process. So then the question becomes how do we do that economically considering some of the environmental regulations to make that extraction and processing cost-competitive on the world market.

I believe you are correct; the rest of the world does not have the same hurdles that we do. Our environment is incredibly important, and we need to protect it. We need to come up with ways to mine more environmentally friendly.

Mr. MCNERNEY. Thanks. Dr. Handwerker, as each critical material has a different supply chain and market structure, can you speak to why it's so important that H.R. 4481 authorize the DOE to develop more comprehensive analysis on market chain?

Dr. HANDWERKER. So, first of all, all of the critical materials are byproducts of similar kind of primary mining operation. And so it's going to be important within H.R. 4481 to really work with those supply chains, including existing mining in the United States, to be able to extract the rare-earth materials that are there in sometimes very low levels, as Dr. Schwartz mentioned. They are there, but the challenge is really how to extract them with these really part-per-million or tens-of-part-per-million level.

So, first of all, the mining supply chain, we really are looking at the Critical Materials Institute more holistically at which of these different primary mining: Copper, iron, niobium, which ones can provide each individual critical material. In terms of the recycling and reuse, yes, each supply chain is going to be different. And so that's why we're focusing on the ones where we can have the highest impact. So, for example, for rare-earths in hard disk drives, in magnets, and hard disk drives, those are—I think we know what a circular economy would have to look like, what the full supply chain would look like.

For engines, that's the primary use of rare-earth magnets in the U.S. We are working on that because those are very different in terms of products, in distribution, so there are many more challenges for those. So, yes, all the supply chains are different, and we have to select which ones to look at.

Mr. MCNERNEY. Can items be manufactured in a way that makes their extraction of rare-earths from the recycled products easier?

Dr. HANDWERKER. Yes, absolutely. So one of the things I'm very proud to be able to report is our collaboration with Seagate, they now have a task force in determining how to reuse the whole magnet assembly in next-generation hard drives. And the Seagate CEO has said they're going to make hard drives from hard drives thinking specifically about the rare-earth magnets and the magnet assemblies.

So, yes, they can be, but it really takes the engagement across the supply chain, and I think Critical Materials Institute has played a leading role in that to show what's possible, how to take the assemblies out, how to put them back into the hard drives. And then if they can't be put into the hard drives, how to create all the different pathways in the supply chain to get them back into new hard drives starting out from the oxides.

Mr. MCNERNEY. As I yield back, I'm going to say that I think Congress should show some leadership in encouraging that behavior in industry. Thank you. I yield back.

Chairman LAMB. Thank you. And I want to thank our colleague Mr. Swalwell for joining us today and offering the legislation that is kind of underlying this hearing. And with that, I recognize Mr. Swalwell for 5 minutes.

Mr. SWALWELL. Thank you. And I thank the Subcommittee Chairman and Ranking Member, as well as Chairwoman Johnson and the Ranking Member of the Committee, for holding this hearing and allowing me as a non-Committee Member but a former Committee Member to participate. This is an issue of great importance to our country, particularly my district with two national laboratories and one that I have worked on for many years.

And I was hoping, Dr. Schwartz, to start with you. When this bill last came to the floor in 2014, there were some concerns expressed about the impact it would have on government interference in the private sector. And I was wondering if you're aware of those concerns and how you would respond to such concerns.

Dr. SCHWARTZ. Thank you for the question. I am not specifically aware of what those concerns are. I have heard that—and there are always debates about what is the role of Federal funding for industrial research. The Critical Materials Institute is focused very much so on the early stage research, but we rely on industrial input and guidance as early as we can get it. In many cases researchers at universities, at national laboratories think they may know what the whole question is, what the whole problem is, but don't understand all of the corporations' research that have gone on for decades and decades and decades. So having that team with industrial input early saying, you know what, we've looked at that part of the problem, don't spend your time and money there. Having that industrial input to say, you know what, when we look out 10 years, 20 years, these are our fundamental challenges, that's where national labs and academia can play the biggest role.

Mr. SWALWELL. Thank you, Dr. Schwartz.

And, Dr. Hayes, you're a great example of the talent that has come out of Lawrence Livermore National Laboratory. And as a researcher and professor of chemistry, could you describe the importance of critical materials not only to our economy but also our national security?

Dr. HAYES. I was not involved in the national security aims at Lawrence Livermore National Labs, but I think Dr. Schwartz may be better able to answer that. But certainly what we have been hearing today is about these many critical elements that come and enable many applications, whether it's for just regular everyday life, new batteries, you know, new types of engines and the like, and also in the national security apparatus of course, those are exotic materials that certainly are on the list.

Mr. SWALWELL. And you are familiar with the annual budget for the Critical Materials Institute, which is $25 million. My legislation would raise the baseline to $30 million with a 5-percent increase each year for 5 years. How would this additional funding benefit research?

Dr. HAYES. So I am not enabled to comment on that.

Mr. SWALWELL. Sure, if Dr. Schwartz wanted to help us with that one.

Dr. SCHWARTZ. There is so much to do, just like there is so much for all of you to do and there's not enough time. There's so much for the national labs to do, for academia to do in terms of that early stage research. I very much appreciate your proposed bill. The Critical Materials Institute would benefit immensely by having that baseline increase. That would allow us to continue to focus on the most critical elements or continuing to develop that critical materials framework that will position this country, that will create that enduring capability to address critical materials as new ones come about.

Mr. SWALWELL. One other issue is our global competitiveness. And within weeks of this bill coming up for a vote in 2014—and we got very close to passing it—China was found in violation by the World Trade Organization for its practices related to rare-earth elements. In fact, in this most recent trade war with China, they have sought and have publicly stated that they would use their rare-earth advantage against the United States. Can any witness talk about how continuing to invest in critical materials innovation could help us have an edge or at least get on the same plane as China?

Dr. SCHWARTZ. So, ideally, just like the United States is striving to and in many cases has achieved energy independence, we would like to have that same independence in everything. We would like to be fully dependent on our own production capabilities, on our own manufacturing capabilities so that we can make the new energy systems, we can make the new technologies and electronics, and we can make defense systems when we need to make it here. We've lost a lot of that capability not because we don't have the natural resources here but because of environmental issues, because of cost of labor. It was more efficient for U.S. companies to outsource. In terms of energy security, national security, I think the United States would benefit by bringing some of that back here.

Mr. SWALWELL. Thank you to all the witnesses. And thank you to the Subcommittee Chair. And also thank you to the staff for working with us over the years to bring this forward. I yield back.

Chairman LAMB. And there's been an interest in a second round of questions at least from Dr. Foster, so, Dr. Foster, you're recognized for 5 minutes.

Mr. FOSTER. Certainly. And thank you. Let's see.

Mr. Weiss, these aluminum-cerium alloys, is there a compromise in the machineability or are the advantages all in casting? Is there any downside to these?

Mr. WEISS. No. There is not a machineability issue with the alloy, the machine, just as other aluminum alloys do. The one downside that we are working on currently is in improving the ductility of those alloys for high toughness type of applications.

Mr. FOSTER. And you mentioned that you have a scheme in R&D for the direct reduction of the cerium carbonates.

Mr. WEISS. Correct.

Mr. FOSTER. Can you say little bit about it?

Mr. WEISS. Yes. And we've done this on a laboratory scale. What we do is we inject the carbonates into the liquid alloy under the surface. The speed of reaction——

Mr. FOSTER. This is during the refining of the aluminum integrated into the——

Mr. WEISS. Once we melt the aluminum at least—so we start with a batch of pure aluminum. We introduce the carbonate under the surface of that melt. The kinetics are such that it pretty much instantaneously changes to metallic cerium. And then the aluminum cerium then are metallic. And then based upon the reduction chemistry, we're left with aluminum oxide, which is not a good thing, and then we remove the aluminum oxide without removing the cerium.

Mr. FOSTER. OK. All right. And so you still ultimately have to get the energy in to reduce it.

Mr. WEISS. Correct.

Mr. FOSTER. OK. All right.

Mr. WEISS. Correct.

Mr. FOSTER. Yes, it sounded like you had some magic around that, but it's basically a simplification of the process.

Mr. WEISS. It's a simplification of the process.

Mr. FOSTER. Right.

Mr. WEISS. It does not require, therefore the way we do things now which is to buy metallic cerium and alloy it in.

Mr. FOSTER. Right. Now, do you find that our patent system is serving you well? You know, you're developing all this neat technology and of course the obvious worry is you'll develop it all, get it going, and then find that China has looked online at all of your publications and set up a big factory that you can't compete with?

Mr. WEISS. I guess it's always a concern.

Mr. FOSTER. Yes. And this is something I struggle with all the time.

Mr. WEISS. Right.

Mr. FOSTER. You know, that we developed all this great technology, and then because of labor costs or environmental costs or some little advantage, all of the real benefit comes not only in the making of the original chemicals but the value-added chain for permanent magnets and so on that have strategically been—so, you know, I think ultimately we have to find some way to gently interfere with the workings of the free market here, that the free market has applied—has—you know, the free market has said, OK, the low-cost worldwide producer of, you know, rare-earth magnets is a place where they don't have environmental regulations and they have low cost of labor. And they can, you know, go on the internet and pull all the intellectual property over for zero cost.

And so under those circumstances we cannot sustain a large class of industries unless we interfere strategically with the workings of the free market. Is there any way around that logic that you're aware of? Do we have to, you know, either subsidize or put quotas on imports or something like that to preserve these industries?

Mr. WEISS. From my perspective the most important part is the research side of it. I mean, as a company that strives to make money, we have to deal with the problem all of the time. And so we have done things like automate our operations and find less-expensive ways to do things. And from the standpoint of this direct reduction, we're looking at the next step is can we automate that process to make it as inexpensive as possible so we are relatively unassailable from the international part.

Mr. FOSTER. Yes, but then you depend on the protection of that intellectual property to work which is another ongoing challenge.

I'd like to change the subject a little bit. I'm really impressed at the wonderful things you're doing in materials science. How is the situation in recruiting the next generation of materials scientists? Do they all want to go and do, you know, machine-learning AI stuff, or do they want to, I guess a generation ago they went into finance. Are you having better luck that way? Do young kids understand the magic of what you're doing and how it can change the world? Dr. Hayes?

Dr. HAYES. I would say absolutely. In my line of work I'm a spectroscopist, but I'm surrounded by so many young people that are just chomping at the bit to get into these problems in part to solve issues related to the environment, to climate change and the like. And so the development of new materials is driven by a large sort of——

Mr. FOSTER. And what fraction of the graduate students that you all work with are foreigners that we're going to send home when they get their Ph.D.s?

Dr. HAYES. In my program, 50 percent.

Mr. FOSTER. Fifty percent is a typical number?

Mr. WEISS. Yes, that's typical.

Dr. SCHWARTZ. Yes.

Dr. HAYES. Yes.

Mr. FOSTER. And so I have introduced legislation to try to fix that. And I look forward to your support. Well, thanks so much, and I yield back.

Chairman LAMB. I recognize Mr. Weber for 5 minutes.

Mr. WEBER. Thank you. Are we going to be able to have a third round do you think? Man, where do we start? Quantum computing—well, let me back up because I'm on the hill of what Bill was saying. I'm really interested in that, especially when he was talking about gently doing something to the free market.

So I want to go to you, Mr. Weiss. If you can tell us, what's the source of most of your aluminum?

Mr. WEISS. Canada.

Mr. WEBER. Canada?

Mr. WEISS. Canada, yes.

Because we deal so much in military products, we are actually restricted from buying aluminum from some sources.

Mr. WEBER. OK.

Mr. WEISS. But nonetheless, we've always bought from Canada and probably if we were doing commercial products, we'd buy it from Canada.

Mr. WEBER. OK. Well, that's good to hear. We're hoping to get the USMCA (United States-Mexico-Canada Agreement) done, just FYI, so I thought I'd get that plug in there.

I want to switch to quantum computing because, you know, last year we passed that H.R. 6227, *National Quantum Initiative Act* about quantum computing. Are each of you using any of that—maybe not you, Mr. Weiss. I don't know. But are you all finding that useful? And what percentage and tell us how that works for you.

Dr. SCHWARTZ. So the legislation I believe is useful from a national laboratory perspective. That is providing instructions and guidance to the national labs, to universities that says the United States thinks that this is a very important direction to pursue. Through the Department of Energy, there have been a number of funding opportunity announcements, a recent one on quantum information sciences. Ames Laboratory won one of those awards on developing new algorithms and codes to work on quantum computers. There is the Energy Frontier Research Center program through basic energy sciences within the Office of Science, Ames Laboratory, and many others recently won a New Center Award to develop topological semimetals which have the potential to contribute to quantum information science.

Mr. WEBER. So you're not there yet, but you see it coming?

Dr. SCHWARTZ. So there are quantum computers out there. Ames Laboratory does not have one. You can purchase a quantum computer I think through a company in the State of Washington. A number of labs do have those existing quantum computers where they are trying to further develop the capabilities.

Mr. WEBER. OK. And do any of you all—and this could be for you, too, Mr. Chairman and you, too, Bill. It seems like a week ago in the news that China cut off exports to Japan of a rare-earth mineral or essential element. Did anybody pick that up in the news? Does that make sense?

Mr. FOSTER. Yes, back in roughly 2010 China cut back the rare-earths for magnet purposes to Japan as some—I can't remember what they were fighting about, but it was——

Mr. WEBER. Yes, I was thinking like in the last week of news I saw it come across my Apple watch of all things.

Mr. FOSTER. Well, it's a threat there that's all the time.

Mr. WEBER. What, my watch or the trade thing?

Mr. FOSTER. No——

Mr. WEBER. Yes.

Mr. FOSTER. No, the Chinese threat. They have the——

Mr. WEBER. Well, I got you.

Mr. FOSTER [continuing]. Japanese by the throat here.

Mr. WEBER. OK. Well, I don't know if you all were paying attention or saw that.

So here's an interesting thought. In your discussion, Dr. Hayes, with Mr. Baird earlier, you talked about using liquid helium and stuff like in some of the high heat areas, so I'm thinking how about waste heat recovery in those applications? Has any thought been given to that?

Dr. HAYES. To the best of my knowledge I do not know of that aspect being capitalized.

Mr. WEBER. No? Anybody else?

Mr. WEISS. I will point out that in the production of aluminum-cerium alloys, which is my thing, that the formation of the intermetallic is exothermic, and therefore, the total heat content per pound of aluminum melted is lower in the aluminum-cerium alloy.

Mr. WEBER. In some of Dr. Schwartz's testimony, he said that CMI researchers discovered a way to reduce the processing temperatures from 3,100 degrees centigrade to 800 degrees centigrade through electrolysis in a molten salt. Do you know what those correspond to in Fahrenheit, 3,100 centigrade?

Dr. SCHWARTZ. Let me get back to you on that one.

Mr. WEBER. OK. You're supposed to know these numbers right off the top of your head, no heat from this end, pun intended.

Dr. SCHWARTZ. That's a National Energy Technology's Laboratory work——

Mr. WEBER. OK.

Dr. SCHWARTZ [continuing]. That I'm less familiar with.

Mr. WEBER. So in those applications there would be some possibility of getting waste heat recovery?

Dr. SCHWARTZ. I suspect the answer is yes.

Mr. WEBER. OK.

Dr. SCHWARTZ. Department of Energy colleagues of mine have been discussing how to take advantage of waste heat for the last few years.

Mr. WEBER. Right.

Dr. SCHWARTZ. And I believe there are relatively small programs funded through DOE, but this is an area that is ripe for additional research. If you look at those Sankey diagrams that show where energy is going, a tremendous amount is going to waste heat. And there are opportunities to do something with that, whether it's create electricity or just put it back into the process for metalworking, for example.

Mr. WEBER. Right. Well, I would suspect that the latter of those two would be the more friendly for what you're doing as opposed to try to put it to the grid. But anyway, these things just fascinate me. So I'm over my time, Mr. Chairman. I appreciate that. I yield back.

Chairman LAMB. I recognize Ms. Stevens for 5 minutes.

Ms. STEVENS. Thank you, Mr. Chairman.

Dr. Hayes, can you talk about the ways in which you work with Federal agencies and which agencies you work with in your helium recycling and storage efforts?

Dr. HAYES. So the National Science Foundation is the major one of course. I am also funded by the Department of Energy, so they are concerned about these aspects. And then at times I've been fortunate to be invited to a helium users meeting here in D.C., and that involved the Defense Logistics Agency showing up and discussing. So I would say those are the three primary ones.

Ms. STEVENS. And I know you talked about this in your testimony. NSF is a funder of yours. And do you know through what programmatic division NSF funds you?

Dr. HAYES. Yes. So math and physical sciences and specifically the Division of Materials Research and also a couple of other ones.

Ms. STEVENS. Yes. And do you know the average annual allocation of award that you're getting from NSF? And how strict are their boundaries for which they're funding you on?

Dr. HAYES. So a typical grant amount is a 3-year grant, and the target amount is on the order of $360,000, so $120,000 per year in this program within the Division of Materials Research.

Ms. STEVENS. And so none of that goes toward labor costs?

Dr. HAYES. Some goes toward labor, absolutely. No, graduate student labor and maybe a little bit of summer salary in my case.

Ms. STEVENS. So no one's getting rich off of that.

Dr. HAYES. Oh, no.

Ms. STEVENS [continuing]. And so they're primarily funding you for the research side of the efforts but nothing for commercial application as—along with DOE, nothing for commercial application?

Dr. HAYES. There are two programs that I've participated in. One is the Energy Frontiers Research Center, as well as the CCI, Centers for Chemical Innovation through National Science Foundation. Both have had strong emphases encouraging us to go into commercial directions. So there are small business partnerships that are nucleated and sort of grow out of those large team assemblies. But as an individual researcher, it is extremely hard on academic timescales to partner with industry. We'd like to, but it's difficult.

Ms. STEVENS. Which we have respect for that. Doctor, the remaining two of you that I know are, you know, directly tied into Federal research endeavors, do you mind just talking a little bit about your work with NSF? I know, Dr. Schwartz, you mentioned NSF in your testimony as well.

Dr. SCHWARTZ. As a Department of Energy national laboratory, we get zero funding through National Science Foundation.

Ms. STEVENS. Zero.

Dr. SCHWARTZ. Zero funding. And it's good. We're a Department of Energy national laboratory. One advantage that Ames Laboratory has is we sit on the campus of Iowa State University, the only lab that actually sits on a campus. And many of our joint researchers are joint faculty members, and they develop understanding, expertise, students, and postdocs through NSF, and sometimes that work is very relevant to the more mission-oriented Department of Energy research.

Ms. STEVENS. Yes. And you're able to have access to it, which is great. Yes.

Dr. SCHWARTZ. Very important, yes.

Ms. STEVENS. Yes. Thank you.

Dr. HANDWERKER. So I've worked extensively with National Science Foundation. I've been at Purdue for 14 years. I've had major interdisciplinary programs in sustainable electronics, which thankfully I've been able to keep up those contacts in sustainable electronics, who are also part of hard disk drives, so we could bring some of these key contacts not only in educating our students, but also in connecting the technologies that they're developing, the science they're doing in actual practice.

So in one program that ended recently we had 30 2-year or 3-year fellows, all U.S. citizens, who got their Ph.D.s working in this program. So, yes, we work extensively with that.

The other thing is that in action number six of the strategic plan, the President's strategic plan for critical materials, it is specifically focused on workforce development. So I've been talking and others at CMI have been talking with people at NSF who were in charge of this workforce development piece to see how we can actually expand the reach for critical materials, mining, recycling, substitution into NSF.

Ms. STEVENS. Right. Well, Dr. Handwerker, we also want to commend you for your educational background, including a bachelor of arts in art history. And now a Ph.D., you know, scientist and you're also working with NIST as well.

Dr. HANDWERKER. And I'm also working with NIST very closely.

Ms. STEVENS. What our Chairman might know is that on the Subcommittee, which I chair, on Research and Technology, which has oversight of NSF and NIST, we are glad to be good funders of the, you know, rare-earth materials and materials work that all of you are doing and want to make sure that that makes its way into future legislation and that competitiveness and productivity and jobs are at the forefront. So thank you all so much. I'm over my time, but this was obviously a good one. I yield back, Mr. Chairman.

Chairman LAMB. Thanks. Dr. Baird for 5 minutes.

Mr. BAIRD. Thank you, Mr. Chair. And this round of questions is going to go to all the witnesses, but this is going to be a ladies-first round, but I want to know what policies that Congress, the Department of Energy, and other relevant Federal agencies might do to encourage industry-led research and development efforts in critical materials research and so on?

But before we do that, Dr. Hayes, I noticed in your testimony that this is the International Year of the Periodic Table. Is that 2018 or 2019?

Dr. HAYES. 2019.

Mr. BAIRD. I noticed that helium was the second element on that, and then you also mentioned that it's very, very small and it can escape anything. Helium can escape anything. So I was wondering if we're doing any research on some kind of container. I'm just kidding you. Back on the question of what policies could Congress and Department of Energy and so on, other Federal agencies do to encourage industrywide research and development? So, Dr. Hayes.

Dr. HAYES. I would start by saying basic research funding has been a challenge over the time of my career. And, you know, I think we need to see increases in that basic research funding and also encourage ties to industry and finding mechanisms to do so. Three-year grant cycles make it difficult to achieve those things.

I might highlight tied to supply chain issues, this is maybe outside the purview of this Committee, but just to highlight that the strategic helium reserve that is being privatized in 2021, here we have an abundant source of helium, one of the top three producers worldwide. You mentioned a container. That is one of the only containers for helium. It keeps it underground, yet we're about to sell it off to a private company that may belong to a foreign entity. And so even though that's outside this Committee's purview, I think that that's something to keep in mind.

So what can Congress do? Maybe keep the container, keep our production capacity of something that we are a leader worldwide. So I'll let others respond with that.

Dr. HANDWERKER. So another important part of research and moving it actually to commercialization and creation of a supply chain is that it goes from research to development and demonstration. And what we've found in many cases is that we're not serving our country well by throwing the technology, the science over the wall and expecting then industry just to be able to take it forward without additional scientific help as they move forward at the development and demonstration stage.

So I think that could be one important policy emphasis in making sure that we maintain those connections during the commercialization stage because in this technology readiness level (TRL), 1 through 4 is the early stage research. To get to commercialization, you've got 5 through 9, and that is where that valley of death happens. And the valley of death happens frequently because something wasn't determined in the early research stage. But if they had access to that research capability, then they could overcome it.

Mr. BAIRD. Thank you. Dr. Schwartz?

Dr. SCHWARTZ. So there are big companies, very large companies that do fund critical materials research. CMI partners with a number of them. Ames Laboratory partners with a few others. And I know that there is significant investment by some of our largest companies in critical materials and other research. Small companies don't have the resources to do that. They simply can't afford. Those small companies often have access to small business incentive programs for jointly funded research.

I think that if there are ways to incentivize U.S. industry to come forward and say these are what the biggest scientific challenges are going out 5 years or 10 years, that would be the areas that universities and national laboratories could have a big, big impact on.

In terms of specific research, in terms of a specific hurdle in order to become profitable or to make a larger impact on the global supply chain, I'm sure policies could be put in place that would—it's something that Representative Foster maybe alluded to—are there ways that Congress or the United States could make U.S. companies more competitive in the international market.

Mr. BAIRD. Thank you. And, Mr. Chairman, could I have Mr. Weiss comment?

Chairman LAMB. Yes.

Mr. WEISS. Yes, I think it's important to emphasize what Dr. Handwerker said about the industrial collaboration. We see—TRL levels are supposed always go up over time as research continues. That's not always the case. You sometimes get it up to a 7, and then you miss a critical piece and you fall back down that chain again. And so at least there is a role for some research in the later stages of development and commercialization, and I think that's very important.

The other comment that I have is the way that the CMI system is set up. It's a bit of a dream team because there are people at the academic institutions and at the national labs that understand some fundamental business economics. So when we have our weekly calls on our program and someone suggests something and I say you can't do that because it's going to cost you $2 a pound, there's an understanding that even though it's a great idea, it's never going to go anywhere. And so we cut off those dead ends very, very quickly by having a very close relationship between the researchers and, in this case, ourselves. Thanks.

Chairman LAMB. Before we bring the hearing to a close, I want to thank our witnesses once more for coming all the way to D.C. to testify for us today. The record will remain open for 2 weeks for additional statements from the Members and for any additional questions the Committee may ask of the witnesses.

The witnesses are now excused, and the hearing is now adjourned.

[Whereupon, at 11:54 a.m., the Subcommittee was adjourned.]

Appendix

ADDITIONAL MATERIAL FOR THE RECORD

LETTER SUBMITTED BY REPRESENTATIVE HALEY STEVENS

umicore

December 10, 2019

The Honorable Haley Stevens
U.S. House of Representatives
Washington, DC 20515

RE: H.R. 4481, Securing Energy Critical Elements and American Jobs Act of 2019

Dear Representative Stevens;

Thank you to Chairman Lamb for holding this hearing and to you, Ms. Stevens, as our elected Member of Congress in Michigan, for providing the opportunity to submit written testimony on this topic.

Umicore is a global energy materials technology and recycling company, with industrial operations employing more than 10,000 people in the United States and around the world. The company focuses on developing "materials for a better life" because we believe that metal-containing materials, which can be efficiently and infinitely recycled, have a vital role to play in creating sustainable products and services, and addressing the global challenges of resource scarcity and clean mobility. Today, Umicore takes in nearly US$4 billion in revenue,[1] 70% of which is from clean mobility and recycling, and we have operations in ten US States: Michigan, Oklahoma, Texas, Massachusetts, Ohio, Tennessee, New Jersey, New York, Alabama, and the U.S. headquarters in Raleigh, North Carolina.

Umicore is a leader in what is called the Circular Economy—the principle of keeping the value of products, materials and resources in the economy as long as possible without having to extract new resources. While we understand that mining is still an important component to the minerals supply chain,

[1] Financial figures can be found in Umicore's annual report here: https://annualreport.umicore.com/performance/key-figures

3600 Glenwood Ave, Suite 250, Raleigh, NC 27612 Phone (919) 874-7171

we believe that recycling will become increasingly crucial, as more and more technological innovation is deployed that requires these materials. Given the exponential deployment of lithium ion batteries alone, and the 10-50 times increase in the number of operating cells we predict by 2025 for rechargeable batteries containing cobalt, nickel, and lithium (all of which we are able to recycle—but some of which, such as cobalt, are often mined in politically unstable areas using unethical practices), recycling will become important from an environmental and humanitarian point of view, and to the global integrated supply chain.

Umicore today is recycling end of life electronics and batteries, spent automotive catalysts, end of life industrial catalysts and other precious metals containing materials to recover and provide a new life to Au (Gold), Ag (Silver), Cu (Copper), Co (Cobalt), In (Indium), Ni (Nickel), Pb (Lead), Sn (Tin), Sb (Antimony), Pd (Palladium), Pt (Platinum), Rh (Rhodium), and other metals in a half million metric ton yearly processing facility in Hoboken, Belgium. Umicore introduced its environmentally friendly battery recycling technology in 2011 and is prepared to recover battery materials from portable electronics, and electric vehicle batteries once they have reached their end of life. Globally, the current fraction of end of life batteries that is recycled is very low meaning cobalt, nickel, lithium and other energy materials are "lost" because these batteries do not find their way to efficient recycling. While recycling cannot completely replace mining, it can complement it and be a sustainable supply of energy materials as the battery industry grows.

I am submitting this letter to offer Umicore's support for H.R. 4481 the Securing Energy Critical Elements and American Jobs Act of 2019,[2] which authorizes Department of Energy (DOE) programs on critical materials recycling, and as this bill is a complementary effort to the President's Executive Order on a Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals,[3] which includes

[2] Full text of the bill can be found here: https://www.congress.gov/bill/116th-congress/house-bill/4481/text?q=%7B%22search%22%3A%5B%22H.R.+4481%22%5D%7D&r=1&s=1
[3] Full Executive Order can be found here: https://www.whitehouse.gov/presidential-actions/presidential-executive-order-federal-strategy-ensure-secure-reliable-supplies-critical-minerals/

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recycling as a key component in understanding and managing our nation's critical resources. Umicore has served as an expert resource, both by submitting written comments,[4] but also through ongoing discussions with the U.S. Geologic Survey (USGS), Department of Defense, and Department of Commerce. To date, the U.S. has had no national policy to set a course for critical minerals recycling and evolution to a circular economy. Only half the U.S. states have any legislation related to end of life electronics and most do not consider lithium ion batteries and other new energy technologies in their policies. While much remains to be done, H.R. 4481 recognizes the importance of recycling and tackles research and programmatic issues that can begin to demonstrate leadership in this country.

As the Committee considers H.R. 4481, Umicore urges particular attention be paid of the benefits of recycling. First, this bill seeks to ensure that the U.S. has a secure, sustainable supply of critical energy materials and focuses on improving the understanding of recycling. Our nation's industrial scrap, end-of-life batteries from cars and energy storage, electronics, and electronic appliances contain valuable resources that could be recycled and put back into the economy. Recycling critical materials found in these products will avoid having to purchase materials mined in unstable parts of the world and provide a home-grown resource stream for those materials. Today China and Russia provide nearly 70% of the world's refinery and production reserves for Germanium while the United States is one of the largest consumers.[5] The recycling of Germanium which Umicore does in Quapaw, Oklahoma helps offset the lack of natural sources for critical applications using Germanium such as 5G fiber networks and Low Earth Orbit satellites.

Second, recovering metals from end-of-life products yields more material per ton than mining from primary resources. For every ton of gold-containing ore taken from the ground through mining, on average less than five grams of gold can be recovered. By comparison, for every ton of mobile phones

[4] Umicore comments can be downloaded here: https://www.regulations.gov/document?D=DOI-2018-0001-0387
[5] See the USGS Mineral Commodity Summaries 2019 (page 68-69) here: https://prd-wret.s3-us-west-2.amazonaws.com/assets/palladium/production/atoms/files/mcs2019_all.pdf

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recycled, we can harvest up to 250 grams of gold, or approximately 50 times the yield from mining. For automotive catalysts, we can recover 400 times the yield in recycling for Platinum Group Metals (PGMs) than we harvest in mining. New electrification technologies—like electric vehicles and energy storage—provide markets for the increased need for battery materials. Electric vehicle sales increased over 80% from 2017 to 2018 in the U.S.[6] The number of vehicles sold in the U.S., however, was dwarfed by China which has 60% of the total electric vehicle market.[7] Bloomberg New Energy Finance increased its prediction of the adjacent energy storage market to $1.7 Trillion by 2040.[8] Thus, the need for materials is clear and only increasing.

Finally, the economic growth benefits of a domestic commitment to the recycling of critical materials could be enormous. The employment potential of a robust U.S. critical materials recycling industry is significant, involving not only a high number of jobs but also employment of varying skill levels at the first three stages of the recycling process: (1) the collection of discarded end-of-life products and scrap; (2) the dismantling and sorting of products and the separation of components; and (3) the pre-treatment of the separated components. Employment possibilities at the fourth stage, the refining (Umicore's business) of the pre-treated materials into the final critical material products, is limited due to the economies of scale needed to economically recycle these materials. In addition to primary jobs, indirect jobs could include supporting services in IT, engineering, transportation, sales, administration, as well as research at universities and research centers.

Umicore believes the federal government has an important role to play in both leadership as well as in research and development. Stakeholder collaboration, public-private partnerships, standards, and a systems approach, will be important to sharing information about these processes and what it will take to

[6] See analysis here: https://www.greentechmedia.com/articles/read/us-electric-vehicle-sales-increase-by-81-in-2018#gs.bmvm7v
[7] See article in Detroit Free Press here: https://www.freep.com/story/money/cars/mark-phelan/2019/03/27/china-electric-vehicles-production/3217195002/
[8] Article from Utility Dive here: https://www.utilitydive.com/news/bnef-raises-forecast-for-global-battery-deployment-to-12t-by-2040/541541/

move toward more sustainable practices. Umicore is delighted that the Department of Energy has taken a greater interest in these issues this year by launching a Battery Materials Recycling Hub at Argonne National Laboratory and supporting a lithium ion battery recycling prize competition, which will promote best practices for the collection and the initial processing of these critical materials. We are also optimistic that, because of this hearing and the discussion about H.R. 4481, we can implement policy that opens up new markets to recycling, creates highly skilled jobs, and secures our critical resources for a clean, safe, and wealthy future for all.

Thank you again for the opportunity to submit this letter. Please do not hesitate to contact me should you have any questions regarding critical minerals recycling.

Respectfully Submitted,

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